Sandra Ide RN

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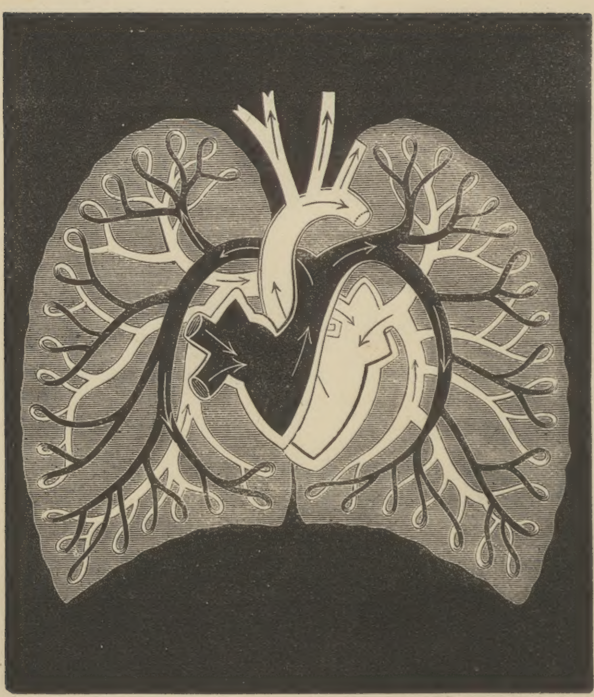
Corbert P. Jefferson

Lowell Eng'l Dept

Sept. 6th 1873

Epiglottis at the
base of the tongue,
leaf shaped.



CIRCULATION THROUGH THE HEART AND LUNGS.

A TREATISE

ON

PHYSIOLOGY AND HYGIENE;

FOR

SCHOOLS, FAMILIES, AND COLLEGES.

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PREFACE.

This book is intended as a means of instruction in Physiology and Hygiene for pupils and general readers who have no previous knowledge on medical subjects. The writer has endeavored to arrange the statements and descriptions in such a way that no anatomical or physiological term should be employed, the meaning of which has not been already explained in the text. For convenience of reference, however, in cases where this explanation may have been overlooked or forgotten, a Glossary is added in the latter part of the book, which contains the meaning of all professional terms employed in the body of the work. A large proportion of the complicated names and phrases required for the complete study of Anatomy and Physiology are entirely unnecessary for those who pursue it simply as a part of their general education—that is, in the same way as they study Geography, Astronomy, or Mathematics. The most important, and, at the same time, the most interesting facts of Physiology may be taught with success in a perfectly simple manner, provided they be given in the proper order and in their natural relation to each other. It has been the aim of the present work to accomplish this object; and if it be found to have succeeded in that respect, it is hoped that it will be an assistance to the teachers, parents, and pupils for whose use it was designed.

New York, 1868.

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INTRODUCTION.

Physiology is the science which teaches us the natural actions of the living body, and the manner in which they are performed. It is very important for us to know what these actions are, and how they take place, for two reasons:

First, because we learn in this way what kind of work the living body is capable of accomplishing, and to what uses it is adapted, so that we may be enabled to employ our natural powers to the best advantage, and not waste them by attempting what is useless or impracticable.

Secondly, by understanding the natural actions of our bodies, and how they are maintained in a healthy condition, we are enabled to avoid injuring them by improper treatment, and thus actually diminishing our vital powers, or exposing them to debility and disease. Nothing can be more important than this either to our comfort, our usefulness, or even our mental improvement. For the bodily frame is the organization by which our animal life is maintained, through which all our knowledge of the world about us is acquired, and by means of which alone all our designs are carried into execution. The knowledge of the mode in which health is to be maintained, and the bodily and mental powers kept unimpaired, constitutes the science of Hygiene.

The study of physiology, therefore, leads directly to that of hygiene, and the two are necessarily associated with each other.

In examining the bodily frame, we easily see that it is composed of various parts, which differ from each other in size, appearance, texture, and location. In one region, for example, there is the heart, in another the liver, in another the brain; while the surface is every where enveloped by the sensitive expansion of the skin. These different parts or portions of the body are called its *Organs*. They are connected in such a way as to give to each other a mutual support, and to form by their union a complete bodily organization.

Now each one of these organs is intended for a particular use, which is necessary in some way to the maintenance of life. Thus the heart circulates the blood, the lungs breathe, the liver produces the bile, the stomach digests the food, and the brain directs the movement of the limbs. The particular act or duty which each organ performs in this way is called its *Function*. Each function is different from every other, just as the organ which performs it is different from the rest; but they are all necessary to the healthy action of the whole body. For the different functions are associated together like the different organs that perform them, and are in the same way mutually dependent. Thus the liver can not produce bile unless it be properly supplied with blood, and the blood will soon become poor and useless unless the stomach continues to digest the food.

The whole body, accordingly, is made up of different organs, united with each other, and performing at the same time a variety of functions. It is a kind of workshop in which various duties are performed by different workmen, while all combine to produce the final result. This result is the complete and healthy activity of the entire frame.

While studying, accordingly, in their regular order, the various animal functions, we find that they are naturally arranged in certain groups, which are distinguished from each other by the nature of the acts performed and the object to be accomplished by them. Some of these acts are comparatively simple, others more peculiar and complicated. We shall find that their study is facilitated by taking up first the more simple of the animal functions, and afterward in succession those which are more complex.

These functions will accordingly be described in four different groups or sections.

Section I.—The animal functions belonging to the first group are entirely Mechanical in their nature. They are those by which the body is held together by the articulation of its various parts; by which the internal organs are protected from mechanical injury; and by which the voluntary movements of the limbs and trunk are performed. This group comprises the functions of the bones, the cartilages, the ligaments, the tendons, and the muscles.

Section II.—The second group of functions are those which are physical or chemical in their nature, and which provide for the nourishment or Nutrition

of the body. This group includes a great variety of functions, which all tend, however, to the accomplishment of a single object, viz., the maintenance of the animal frame in its proper condition of flesh, strength, and activity. We shall study, in this division of the subject, the ingredients and qualities of the food, its preparation, digestion, and absorption, the blood and its circulation, respiration, secretion, and the nutrition of the animal tissues.

SECTION III.—The third group includes the actions of the NERVOUS SYSTEM. These actions are quite different in their nature from any of the preceding, and have for their ultimate object the guidance or regulation of the other functions. It is in the study of this group that we shall learn the action of the senses, of the will, of the instincts, of many involuntary movements, and of the various operations of the mind.

SECTION IV.—Finally, an important division of the subject is that which relates to the changes in the functions of the body at different ages, to its growth, adolescence, maturity, and DEVELOPMENT. For the history of the animal functions is not entirely the same at different ages, but undergoes various modifications, like the external appearance of the frame, and the capacity of the mental and bodily powers. The entire organization, therefore, is adapted to different purposes at different ages, somewhat in the same way as the various organs are permanently devoted to particular functions.

Section I.

MECHANICAL FUNCTIONS.

PHYSIOLOGY AND HYGIENE.

CHAPTER I.

GENERAL STRUCTURE AND MECHANISM OF THE ANIMAL FRAME.

THE BONES.—Their Composition.—Their Structure.—The Skeleton.—Spinal Column.—The Skull.—Pelvis.—Tibia.—Bones of the Foot.—Curvatures of the Skeleton.—Elastic Ligaments.

THE MUSCLES.—Their Contraction.—Relaxation.—Flexor and Extensor Muscles.—Tendons.—Movement of Joints.—Walking.—Running.—Leaping.—Elasticity of the Skeleton.—Exercise of the Muscular System.—Its Repose.

1. **Structure and Composition of the Bones.**—The body depends for its general form and solidity upon the *bones.* The bones are of various sizes and shapes in different parts of the frame, but they are distinguished from the other organs by being hard and rigid, instead of soft and yielding; so that they are adapted to sustain the other tissues which are attached to them, and to protect the internal organs which they inclose more or less perfectly in interior cavities. Now the bones have this important quality of hardness and rigidity because they contain, among other substances, a large proportion of a mineral ingredient. This ingredient is *Lime*, which, in certain forms of combination, is united with the animal matter of the bones, and makes them firm and resisting. If the bones were composed entirely of

this mineral ingredient, they would be stony and brittle, like limestone or marble; but, in reality, they consist partly of animal matter and partly of lime. The lime gives them their stiffness and resistance, while the animal matter makes them, at the same time, somewhat tough and elastic; so that they combine, to a certain extent, the two qualities of stiffness and elasticity. They are hard enough to sustain the weight of the body, and yet are not so brittle as to be easily broken. As a general rule, the bones are composed of about one half animal matter and one half mineral substance.

Another important quality of the bones is their *lightness*, which is combined in a proper degree with firmness and resistance. If they were entirely dense and solid, they would be too heavy for motion, and would be rather a load and impediment to the animal body than a support and assistance. But, in point of fact, the bones are hollow (Figs. 1 and 2). They are covered every where on their exterior with a layer of very compact bony tissue, which acts as a firm and resisting shell, while in their interior there are cavities occupying a large portion of the bony mass. In the middle of the bones of the limbs these cavities are elongated and cylindrical, and are filled with a soft vascular substance termed the *Marrow;* but their rounded ends contain a multitude of small bony needles and filaments, which branch and unite in various directions, dividing the principal cavity into a great

Fig. 1.

Thigh-bone, sawn open lengthwise.

number of smaller spaces, and giving to the bone in this situation a very finely reticulated or honey-combed

Fig. 2.

Lower end of the thigh-bone, sawn across, showing its central cavity.

structure. By this means the bones are made lighter, while they also preserve their firmness and resistance, and at the same time give a secure fastening to the muscles and tendons which are attached to their surface.

2. **General arrangement of the Skeleton.**—The bones are united to each other, by strong fibres or ligaments, into a connected series or system, which is called the *Skeleton.* The skeleton is therefore a bony scaffolding or frame-work, which sustains by its physical solidity the other organs, and which gives its general configuration to the entire body. It consists, first of all, of the "spinal column," or *Back-bone* (Fig. 3), which runs up and down along the middle line of the back, and which can be readily felt in that situation, like a bony ridge, extending from the back of the neck to the region of the hips. This ridge is formed by a line of sharp prominences or "spines," each of which belongs to a separate bone; and as these bones are placed one upon

Fig. 3.

Diagram of the skeleton, etc., in profile. The dotted lines show the direction of the principal muscles.

another, like a pile or column, the entire series has accordingly received the name of the "spinal column." The bones of the spinal column, twenty-six in number, are articulated and locked together by various projections, and fastened by ligaments in such a way that it is capable of being maintained with security in the erect position. It stands, therefore, as a kind of central upright pillar, around which the other organs of the body are grouped, and upon which they depend for their support. It is the most important part of the whole skeleton.

The spinal column sustains upon its upper extremity the "cranium," or *Skull*, which is a hollow bony case containing the brain, and having attached to it the jaws and other parts of the frame-work of the face. Its lower extremity rests upon the "pelvis," or *Hip-bone*, between the two halves of which it is fastened like a wedge, and secured by strong ligaments. The pelvis is a bony expansion, very much like a basin in shape, and is intended to receive and support the organs of the lower part of the abdomen. By placing the hands upon the hips, we can easily feel the flaring edges of this basin-like bone, and can readily understand how it serves to support the intestines and other organs placed above it.

PHYSIOLOGY.

JANUARY, 1874.

1 How are the bones fastened together? Describe the contraction of a muscle. What joints move in a circle? Why is exercise of the muscles necessary to health?

2 Name four inorganic ingredients of the food. What is a ferment? Why is bread fermented with yeast? Name the necessary qualities of wholesome food.

3 What is mastication? Describe the act of swallowing.

4 Name two conditions requisite for healthy digestion. What are the *lacteals* ? What is *chyle* ? By what two routes is the chyle conveyed into the circulation?

5 Define coagulation. Why is it an important property of the blood?

6 Describe the larynx. During respiration what change takes place in the air? What in the blood? What is necessary for good ventilation?

7 Which division of the heart is strongest and why? Explain the use of the valves of the heart. Describe the course of the blood in the circulation.

8 How is the heat of the body produced? How is it regulated?

9 Name the divisions of the brain. Which is most important and why? Why are the internal organs affected by exposure of the body to cold and wet?

10 Describe the iris. Explain the use of the *conjunctiva.*

The pelvis, in its turn, rests upon the "femur," or great *Thigh-bone;* the largest and strongest single bone in the whole body. It is placed nearly straight up and down, and is surrounded by the thick muscles of the thigh. It is itself supported by the *Tibia*, or leg-bone, upon which it is placed, end for end. The tibia is somewhat triangular in shape, and forms the sharp ridge which may be felt on the front part of the leg below the knee. Lastly, the lower end of the tibia rests upon the bones of the *Foot.* These bones are arranged very much in the form of an arch; for while the foot touches the ground by the point of the heel behind and the ball of the toes in front, the bones between them rise into a curved figure, forming at this part an arch or vault, called the "hollow of the foot."

Now the bones of the foot are not fastened immovably to each other, but are so connected by elastic bands and ligaments that they yield a little when pressed upon, and again resume their usual position when the pressure is taken off. We can perceive this very distinctly by bearing down upon the foot forcibly from above, when it spreads out a little, and afterward recovers itself and returns to its original shape.

The principal internal organs, such as the heart, lungs, liver, stomach, and intestines, are contained in the cavities of the chest and abdomen, being situated in front and on the sides of the spinal column.

3. **Balancing of the different parts of the Skeleton.**—The entire skeleton, therefore, forms a connected series or vertical frame of bones, which is so balanced that it may be kept in an upright position.

The different parts of the skeleton are not placed exactly in a straight line, one above another, but, on the

contrary, vary somewhat both in a backward and forward direction. The bones of the foot are placed very obliquely, as we have already seen, forming an arch. The tibia, which rests upon this arch, is the only bone which is exactly vertical. The femur is somewhat curved in shape, and is also tipped forward, so that its upper extremity is articulated with the pelvis a little in front of the junction of the pelvis with the spinal column above. And the spinal column itself has no less than three different curvatures, which are turned alternately in the backward and forward direction. Nevertheless, if we look at the diagram of the skeleton in Fig. 3, we shall see that all these variations compensate for each other; so that, although the skeleton is thus curved in its different parts, its general direction is a straight one, and the weight of the head and upper part of the body rests almost exactly above the ankle-joint.

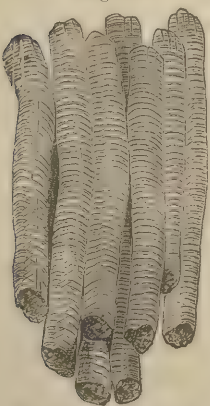
But, as the different parts of the skeleton are movable at the joints or articulations, they must be fixed or steadied in some way, in order to keep the body in an upright position. This is accomplished by the following means.

4. **Action of the Elastic Ligaments.**—First of all, the body is held erect by a series of *Elastic Ligaments*, which are attached to the back part of the spinal column. This jointed column is so arranged that it is capable of moving in various directions, and especially of bending forward; and as the principal internal organs are situated in front of it, their weight would naturally cause it to bend over in this direction. But the spinal column is also provided throughout its entire length with bony eminences, projecting backward from

its posterior surface. Now between these eminences there are attached, from one end to the other, a succession of strong ligaments or bands, called the "elastic ligaments of the spinal column," because they are extensible and elastic like India-rubber. These ligaments are sufficient to prevent the spinal column from yielding to the weight of the organs situated in front. When the back bone is bent forward by the action of the muscles, the bony eminences on its posterior surface, of course, are opened and separated from each other like the sticks of a fan; but afterward they are drawn together as before by the elastic force of their ligaments, and the spinal column is again straightened.

5. **Structure and Action of the Muscles.**—Secondly, the skeleton is maintained in its upright position by the action of the *Muscles.* These are the organs which are attached to the different parts of the skeleton in such a way as to control its movements. They form a large proportion of the whole mass of the body, and constitute the firm and ruddy fibrous *Flesh*, which is found every where underneath the skin, which clothes the bones, and which envelops in a kind of muscular sac the cavities of the chest and abdomen.

Fig. 4.



Muscular fibres highly magnified.

If the muscles be examined by the microscope (Fig. 4), they are seen to be composed of a great number of very small *fibres*, too minute to be seen by the naked eye, placed side by side, and all running in nearly the same direction.

These fibres are ruddy in color, and very elegantly marked by transverse lines or stripes, which run around them in a circular direction. The fibres themselves are united into small bundles, of from 100 to 200 each, which are placed side by side with other similar bundles, but separated from them by a thin layer of loose intervening tissue, called *Cellular Tissue.* A number of these bundles are also united into larger bundles with cellular tissue between them, and these again into still larger. Thus the entire muscle is made up of many bundles of parallel fibres, which can be separated from each other by careful dissection, and reduced to finer and finer divisions, until they become too small for the naked eye. It is this which gives to the muscular flesh its fibrous appearance on close examination.

Now the muscles, as we have described them above, are endowed with the power of *Contraction.* By this it is meant that the muscular fibres, when they are excited by the influence of the will, can shorten themselves, so as to draw together any two points to which their ends are attached. Both ends of a muscle are never attached to one and the same bone, but between their two attachments there is always an articulation or joint, which allows of motion between one bone and the other.

In contracting, therefore, the muscle draws the two bones to which it is attached nearer to each other.

Whenever a muscle contracts, it swells from side to side at the same time that its fibres are shortened; and very accurate experiments have shown that it increases in thickness in exactly the same proportion that it diminishes in length. It does not become, therefore, either larger or smaller during contraction, and only changes its shape, but not its size.

If we grasp with the fingers the muscles on the front part of the arm above the elbow, we can perceive their contraction whenever we bend the elbow forcibly upward. At this time two changes in the muscle are distinctly felt. First, it swells, as we have already said, and becomes prominent under the skin; and, secondly, it becomes at the same moment harder and more resisting to the touch. This increased hardness of the muscle during contraction is caused by the forcible tension of its fibres, which continues as long as they remain in activity.

The action of a muscle, accordingly, during contraction is as follows: it shortens in the direction of its length, enlarges in the direction of its thickness, and becomes more tense and firm in consistency.

A muscle can remain in contraction only for a short time. After a few instants it returns to its former condition, becomes comparatively soft and yielding, and ceases to exert its force, so that it may be easily drawn out to its former length. This state of the muscle is called its *Relaxation;* and when completely relaxed, its fibres no longer exert any active effect upon the parts to which they are attached.

Every muscle, accordingly, is alternately in one of two different states, viz., the state of active contraction or that of passive relaxation.

6. **Arrangement and Action of the Flexors and Extensors.**—Nearly all the muscles of the body and limbs are so arranged in two different sets as to act alternately with each other. One of these two sets is placed on the anterior, or front part, the other on the posterior, or back part; and when thrown into activity, they serve to move the limb in two opposite directions.

Those which bend the joint are called the *Flexor* muscles; those which straighten it are called the *Extensor* muscles. Thus the muscles on the back part of the thigh draw the leg backward and bend the knee; they are therefore the flexor muscles. Those on the anterior part of the thigh draw the leg forward and straighten the knee; they are therefore the extensor muscles. On the other hand, the muscles on the front part of the arm, above the elbow, bend the arm at the elbow, and are flexors; those on the back part straighten the elbow, and are extensors.

In this manner the movements of the body are accomplished by the alternate contraction and relaxation of the two sets of muscles operating in different directions; for when the flexors contract, they bend the limb without any resistance from the extensors; and when the flexors become relaxed, the extensors again straighten the limb as before. When both flexors and extensors are thrown into activity at the same moment, they make the limb rigid, and prevent its moving in either direction.

But, as we have already seen, a muscle can remain in constant action for only a few seconds at a time. After a short period it must again become relaxed, not only to allow the opposite muscle to bend the limb in a different direction, but also to gain for itself new strength for another movement; for the force of the muscular fibres is more or less exhausted during contraction, and again restored during relaxation. The muscles, therefore, alternately expend their power while contracted, and regain it in the state of relaxation. It is on this account that it is so exhausting to hold the arm or the leg outstretched in the same position for

several minutes together, while the same limb may be moved backward and forward during an equal period without any sense of fatigue. For the same reason, it is more tiresome to stand upright and motionless for a quarter of an hour, than to walk about for the same length of time.

In the ordinary movements of the body, therefore, the different muscles are constantly changing from contraction to relaxation, and their natural vigor is thus kept unimpaired.

Accordingly, it is easy to see how the skeleton is held erect by the action of the muscles. The effect of this action is not that of a rigid and unyielding stiffness, but a delicate and graceful balancing, which allows of constant changes and inclinations of the body, without its being thrown out of the upright position. Those muscles which are situated in front prevent the joints from bending backward, and those which are attached behind prevent their yielding in a forward direction. In the same manner, those which are placed upon the right and left sides of the body prevent its falling in either direction laterally. The muscles are like the stays which support the masts of a ship, only they are not inanimate and passive, but active and movable in controlling the different parts of the skeleton. The body can not remain upright for a single instant without their aid; for, if the muscles be paralyzed at any time, as by an apoplexy, or a sudden blow upon the head, the power of standing erect is instantly lost. The head falls down upon the chest, the spinal column bends forward, the thighs bend at the hip-joints, the legs give way at the knees, and the entire frame falls together in a collapsed and shapeless mass. But

while the muscles retain their natural action by constantly drawing upon the different parts of the limbs and trunk, alternately backward and forward and from side to side, they prevent any undue deviation, and maintain the body in the erect posture.

7. **Attachment and Mechanism of the Muscles.**—The muscles of the limbs are usually rather elongated in shape, and somewhat thinner at their two extremities than in the middle. At their upper extremities, as a general rule, they are quite closely attached to the bones; but at their lower extremities they become more slender and tapering, and run into somewhat long and narrow rounded cords of white fibrous tissue, which are called "sinews," or *Tendons.* These tendons have no power of contraction like that of the muscular fibres, nor can they be stretched like the elastic ligaments of the spinal column; they are simply very strong and unyielding fibrous cords, by which the muscles are attached to the bones upon which they are to act. When a muscle contracts, accordingly, it draws upon the bone below, by means of the tendon which is inserted into it, exactly as a horse draws a loaded wagon by means of the leathern tugs and couplings of his harness.

The tendons are usually inserted into the movable part of a limb, at a short distance below the joint. Accordingly, when the muscles contract, they act upon the limb with great rapidity; and a small amount of contraction in the muscle will move the farther extremity of the limb over a considerable distance. Thus the hand and arm are raised, in bending the elbow-joint, by the action of the flexor muscles situated on the front of the upper arm, above the elbow, called the *Biceps flexor* and the *Brachialis anticus* (Figure 5). They

Fig. 5.

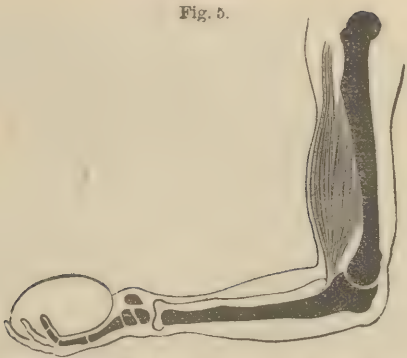


Diagram of the arm bent at the elbow, showing the action of the flexor muscles.

arise from the bones of the shoulder and upper arm, whence their fibres pass in a downward direction, their tendons being finally inserted into the bones of the fore-arm just below the elbow-joint. When these muscles contract they draw the fore-arm upward, moving it upon the elbow-joint like a door upon its hinges, and thus raising any weight which is supported upon the hand or wrist. The greater the weight which is to be lifted in this way, the greater the force which is exerted by the muscles; and they may be felt, accordingly, on the front of the upper arm, swelling and hardening at the moment of contraction exactly in proportion to the amount of strength put forth. The tendon of the biceps may also be felt at the same time, just in front of the elbow-joint, made tense and rigid like a bowstring by the action of the muscle above.

Nearly all the movements of the body and limbs are performed by a mechanism like that just described. Whatever variations occur are mainly due to the different construction of the joints; for, while some of

them, as the elbow-joint and the knee-joint, are so arranged that they can move only backward and forward like hinges, others, such as the shoulder and hip joints, can be turned in various directions, or even carried round and round in a circle, or rotated by a kind of twisting motion, like the hand and fore-arm. But in all cases this is accomplished by the action of muscles, whose tendons are inserted into the bones in various directions, and which thus produce by their contraction the corresponding movements.

8. **Movements of Walking, Running, and Leaping.**—The movements of *Walking*, *Running*, *Leaping*, etc., are performed as follows: When the body stands upright, as in Fig. 3, the feet are planted flat upon the ground, bearing at once upon the heels behind and the ball of the toes in front, the weight of the body resting between the two, upon the middle of the arch of the foot. The body is maintained in this position, as we have seen, by the various muscles, which act in such a way as to keep its different parts carefully balanced, and to retain the weight of the whole suspended exactly over the ankle-joint.

Now in walking, when a movement is to be executed in advance, the body is first made to lean a little forward, so that its weight no longer remains above the ankle, but is thrown forward so as to rest entirely upon the toes. The heel is then lifted from the ground by the action of the very strong muscles situated on the back part of the leg, called the *Gastrocnemius* and *Soleus* muscles. These muscles, which come down from above, form the fleshy mass which is known as the "Calf of the leg." They terminate in a strong cord-like tendon, called the "Tendon of Achilles," which is easily felt at

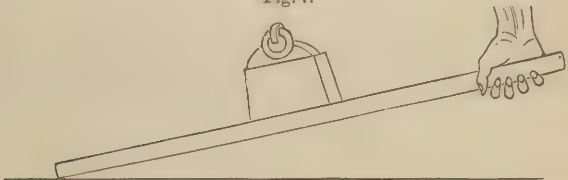
Fig. 6.

Diagram of the foot and ankle, with the heel drawn up by the "Tendon of Achilles."

the back part of the ankle-joint, and which is attached to the projecting bone of the heel, termed the *Calcaneum* (Fig. 6). When these muscles contract, they draw the heel upward by means of the tendon inserted into it, and lift in this way the ankle-joint and the whole body, carrying it upward and forward, its principal weight resting, as already mentioned, over the ball of the toes.

The action of the leg and foot, in this movement, is the same with that by which we might lift a weight from the ground with the aid of a lever. Suppose one end of a strong stick to rest upon the ground, and that this stick bears upon its middle a heavy weight (Fig. 7).

Fig. 7.



Then, by taking in the hand the other end of the stick, we may lift the weight exactly as the body is lifted, in walking, by the muscles of the leg and the ankle-bones.

At the moment that the body is raised and tilted forward in this way, the other foot is lifted entirely from the ground and swung forward, so as to take a step in advance. As soon as the body has been carried far enough in an onward direction, the second foot is

also raised in the same manner as before, while the first is swung forward in its turn to take another step. In this way the two legs act alternately, the weight of the body being carried forward first by one and then by the other; all the muscles, however, upon the two sides combining harmoniously in their action, so as to produce an easy, graceful, and continuous movement.

In the act of walking, as above described, one foot is always upon the ground, and the weight of the body is mainly supported in this way by bearing upon the toes; it is only lifted forward alternately on the two sides by the leverage of the bones of the foot. Consequently no violent muscular exertion is required, and the movement can be kept up for a long time without fatigue.

The act of *Running*, however, instead of being a series of steps, is performed by a succession of leaps or springs, in each of which the whole body is thrown clear of the ground, and carried forward by the impetus which it has received. In order to accomplish this, at the moment the heel is about to be raised by the action of the muscles above described, the knee and hip joints are first bent, and then instantly straightened by the sudden contraction of their extensor muscles. The whole limb thus acts like a powerful spring, which, by its sudden extension, throws the entire body off the ground and carries it through the air in an onward direction. The opposite limb is at the same time thrown forward to receive the weight of the body, and to perform, in its turn, and with a similar rapidity, the same movements. The speed of the runner depends on the vigor of the muscular contractions, and the swiftness with which the successive motions are performed.

The act of *Jumping* is accomplished in a similar way

with that of running, except that the same motions are executed by both limbs together, so that each leap is performed by itself, and is not combined with the others into a continuous movement.

9. **Elasticity of the Skeleton.**—In all these various movements, the body is protected from the effect of sudden shocks and jars by important peculiarities of structure and function.

First of all, the bones themselves are elastic. This elasticity is not very marked in degree for any single bone, but still it exists every where, and is a quality of considerable importance for the entire skeleton. It is owing to the fact which has already been mentioned, viz., that the bones are formed of an animal substance united with a combination of lime. The elasticity of the animal substance is much diminished in consequence of its union with the mineral ingredient; but still it does not disappear altogether, and the entire bone therefore retains the property to a certain degree. In children and very young persons the quantity of lime in proportion to the animal substance is smaller than in adults, and their bones are consequently more flexible and elastic than at a later period. It is for this reason that the bones of young children are very seldom broken by falls or other accidents, while those of adults are more liable to injury from this cause.

Secondly, the articulating ends of the bones are covered with a layer of firm, India-rubber-like substance, called *Cartilage.* In most of the movable joints there are two of these cartilages, firmly attached to the corresponding bones, and moving smoothly and easily upon each other by their opposite surfaces, which are lubricated with a transparent fluid. In the spinal col-

umn the principal cartilages are quite thick and pulpy, lying, like so many elastic cushions, between the different bones of which the column is composed. All these cartilages serve to receive the shock of sudden blows or falls, and to dissipate their injurious effects.

Thirdly, the *Curvatures* of the different parts of the skeleton have also an important influence in this respect. These curvatures are especially marked in the spinal column, which, in its natural position, is bent alternately in three different directions (Figure 3), thus presenting a wavy or serpentine figure instead of a straight vertical line. The consequence of this is that, when it receives a sudden shock or impulse, it yields momentarily by increasing its curvatures, like a bow or spiral spring, and then recovers itself when the pressure is relieved. All the bones of the limbs are also slightly curved in their figure, and therefore contribute, in some degree, to the same effect.

10. **Protective Action of the Muscles.**—Lastly, an important protecting influence is exerted by the action of the muscles; for in leaping, running, or jumping from a high place, the body is never abandoned entirely to its own unassisted weight. The muscles are always employed in holding the limbs in the required position, and keeping them in readiness for other movements. When the body reaches the ground, the limbs bend at the joints, still controlled, however, by the extensor muscles; and these muscles immediately afterward react, again bringing the body into an erect position. In this manner a certain kind of elasticity, dependent upon muscular vigor, is communicated to the motions of the whole frame, and protects it from the effect of sudden concussions.

11. **Exercise.**—The natural force of the muscular system requires to be maintained by constant and regular *Exercise.* If all the muscles, or those of any particular part, be allowed to remain for a long time unused, they diminish in size, grow softer, and finally become sluggish and debilitated. By use and exercise, on the contrary, they maintain their vigor, continue plump and firm to the touch, and retain all the characters of their healthy organization. It is very important, therefore, that the muscles should be trained and exercised by sufficient daily use. Too much confinement by sedentary occupations, in study, or by simple indulgence in indolent habits, will certainly impair the strength of the body and injuriously affect the health. Every one who is in a healthy condition should provide for the free use of the muscles by at least two hours' exercise each day; and this exercise can not be neglected with impunity, any more than the due provision of clothing and food.

The muscular exercise of the body, in order to produce its proper effect, should be *regular and moderate in degree.* It will not do for any person to remain inactive during the greater part of the week, and then take an excessive amount of exercise on a single day. An unnatural deficiency of this kind can not be compensated by an occasional excess. It is only a uniform and healthy action of the parts which stimulates the muscles, and provides for their nourishment and growth. Exercise which is so violent and long-continued as to produce exhaustion or unnatural fatigue is an injury instead of an advantage, and creates a waste and expenditure of the muscular force instead of its healthy increase.

Walking is therefore one of the most useful kinds of exercise, since it calls into easy and moderate action nearly all the muscles of the body, and may be continued for a long time without fatigue. Riding on horseback is also exceedingly efficacious, particularly as it is accompanied by a certain amount of excitement and interest which acts as an agreeable and healthy stimulus to the nervous system. Running and leaping, being more violent, should be used more sparingly. For children, the rapid and continuous exercise which they spontaneously take in their various games and amusements in the open air is the best. The exact quantity of exercise to be taken is not precisely the same for different persons, but should be measured by its effect. It is always beneficial when it has fully employed the muscular powers without producing any sense of excessive fatigue or exhaustion.

It should be remembered, also, that the object of exercise is not the mere acquisition or increase of muscular strength, but the proper maintenance of the general health. A special increase of strength may be produced to a very great extent by the constant practice or training of particular muscles. Thus the arms of the blacksmith and the legs of the dancer become developed in excessive proportions; and by the continued practice, in a gymnasium, of raising weights, or carrying loads, the muscular system generally may be greatly increased in force. But this unusual muscular development is not necessary to health, and is not even particularly beneficial to it. The best condition is that in which all the different organs and systems of the body have their full and complete development, no one of them preponderating excessively over the others. The most useful kind

of exercise, accordingly, is that which employs equally all the limbs, and cultivates agility and freedom of movement, as well as simple muscular strength.

In all cases, also, the exercise which is taken should be regular and uniform in degree, and should be repeated as nearly as possible for the same time every day.

12. **Repose.**—The muscular system requires, furthermore, a daily period of *Repose.* This is not only the interval between the periods of active exercise; for even while sitting, or standing, or engaged in ordinary quiescent occupations, we constantly employ some degree of muscular exertion. It is also necessary that all muscular activity be entirely suspended for a time, during the period of sleep; for it is during sleep that the main part of the nourishment of the tissues takes place, and the renovation of their active powers is accomplished. We feel, accordingly, a sense of refreshment and renewed vigor after sleep, which is owing in great measure to the nourishment and repair of the muscular system. A privation of this necessary repose will inevitably show its effect, after a day or two, in diminished strength and the failure of the powers generally. The requisite amount of sleep, therefore, should always be taken at night with the same regularity that exercise is employed during the day; for it is by the uniform and alternate influence of both that the muscular system is kept in the highest condition, and the general health most effectually secured.

QUESTIONS FOR CHAPTER I.

1. What is the use of the bones?
2. How do they differ in consistency from the other organs?
3. What ingredient gives them their hardness?
4. What ingredient gives them their elasticity?
5. Are the bones solid or hollow?
6. What are their hollow parts filled with?
7. How are the bones fastened to each other?
8. What name is given to the whole series of bones united together?
9. What is the most important part of the skeleton?
10. Why is it called the "spinal column?"
11. What is supported upon the upper end of the spinal column?
12. What is contained within the cranium?
13. What does the lower extremity of the spinal column rest upon?
14. What is the shape of the pelvis?
15. What organs does the pelvis serve to support?
16. What is the bone of the thigh?
17. What is the bone of the leg?
18. What is the form of the bony framework of the foot?
19. How does the foot move when pressed upon?
20. Are the different parts of the skeleton straight or curved?
21. How is the skeleton held upright?
22. What are the "elastic ligaments," and where are they situated?
23. What are the muscles?
24. Of what are they composed?
25. What is the appearance of the muscular fibres?
26. What peculiar property is possessed by the muscles?
27. What effect is produced on the bones by the contraction of the muscles?
28. When a muscle contracts, how is its *shape* altered?
29. How is it changed in *consistency?*
30. What is the relaxation of a muscle?
31. What is the difference between a flexor muscle and an extensor muscle?
32. When the flexor muscles and extensor muscles both contract at the same time, what effect do they have on the limb?
33. When is the force of a muscle expended?

34. When is it restored?

35. Why is it tiresome to hold the arm or leg continuously in one position?

36. How do the muscles serve to balance the different parts of the skeleton?

37. By what are the muscles attached to the movable bones?

38. Where are the muscles situated which bend the elbow?

39. Where are their tendons inserted?

40. What joints move like a hinge?

41. What joints can be moved round in a circle?

42. How is the motion of walking performed?

43. How is the motion of running performed?

44. How are the motions of leaping and jumping performed?

45. How is the body protected from shocks and jars?

46. Why are the bones of children more elastic than those of adults?

47. What are the ends of the bones covered with?

48. What is the use of the *cartilages?*

49. What is the use of the *curvatures* of the skeleton?

50. How do the *muscles* protect the body from injury?

51. Why is exercise of the muscles necessary to health?

52. How should the exercise be taken?

53. What are the most useful kinds of exercise?

54. Why is repose necessary to health?

55. What effect is produced by a want of natural sleep?

Section II.

FUNCTIONS of NUTRITION.

CHAPTER II.

THE FOOD AND ITS INGREDIENTS.

Inorganic Substances.—Water.—Salt.—Lime.—Other Inorganic Matters.—Starch.—Its different Varieties.—Properties of Starch.—Its conversion into Sugar.—Sugar.—Whence obtained.—Proportion in the Food.—Fermentation of Sugar.—Fats.—Stearine.—Margarine.—Oleine.—Crystallization of Fat.—Emulsions.—Condition of Fat in Animal and Vegetable Tissues.—How extracted.—Adipose Tissue.—Proportion of Fat in the Food.—Albuminous Matters.—Different kinds.—Coagulation.—Ferments.—Putrefaction.—Proportion of Albuminous Matters in Food.—All the nutritious substances necessary to Life.

13. **Nature and Necessity of Food.**—Under the term "food" are included all those substances, both solid and liquid, which are necessary for the nutrition of the body. The constant action of the different organs in the living body requires a regular supply of nourishment, by which their strength and activity may be maintained; for these organs can not perform their allotted functions without undergoing a corresponding waste of material, and this waste must be made good by an appropriate supply, if the organs are to retain their powers, and the functions of life continue.

The expenditure of material which thus takes place in the living body is not a simple physical disintegration, as when the wheels and axles of a carriage wear out by mechanical friction; it is a kind of internal decomposition, which pervades every part of the animal

frame, and which is very nearly proportionate in amount to the activity of the organs themselves. It is somewhat like the consumption of water and fuel by a locomotive engine, the water and fuel being used up and converted into smoke and steam, in order to enable the machine to do its work. Somewhat in a similar way the active functions of the living body create a constant demand for nutritious food, which must be supplied with regularity in order to preserve them in continued action.

It is important to know, therefore, what are the necessary ingredients of the food, how they are prepared and combined, and in what manner they are absorbed and consumed by the living body.

14. **Inorganic Substances.**—In the first place, the food contains a large proportion of materials which are called *Inorganic Substances.* They are substances which are found every where in external nature, and which form a portion of the rocks, earth, and running streams. It is on this account that they are termed inorganic substances, because they occur in unorganized bodies, and are not peculiar to animated beings. They are found, however, also in the bodies of living animals, and therefore they must be present in similar proportions in the food, for it is from this source alone that all the materials of the animal frame are necessarily derived.

The first and most abundant of these inorganic substances is *Water.* Water is universally present in all the solids and fluids of the body. It is especially abundant in the blood and secretions, for it gives them their necessary fluidity, and enables them to dissolve all the important materials which they contain.

But it is also an ingredient of the solid tissues; for

if we take a muscle or a cartilage, and expose it to a gentle heat in dry air, it loses water by evaporation, diminishes in size and weight, and becomes dense and stiff. Even the bones and teeth lose water by evaporation in this way, though in smaller quantity. In all these more solid parts of the body, the water which they contain is useful by giving them a certain degree of softness and flexibility, which is necessary to their usefulness. Thus a tendon, in its natural condition, is white, glistening, and opaque; and, though very strong, perfectly flexible. If its water be expelled by evaporation it becomes yellowish in color, shriveled, semitransparent, inflexible, and totally unfit for performing its mechanical functions. The same thing is true of the skin, muscles, cartilages, and other soft parts.

The following list shows the proportion of water in different solids and fluids:

QUANTITY OF WATER IN 1000 PARTS IN

Teeth	100	Bile	880
Bones	130	Milk	887
Cartilage	550	Pancreatic juice	900
Muscles	750	Lymph	960
Ligaments	768	Gastric juice	975
Brain	789	Perspiration	986
Blood	795	Saliva	995

According to the best calculations, water constitutes, in the human subject, between two thirds and three quarters of the entire weight of the body.

Accordingly, water is also a very important element of the food. We require every day nearly three pounds and a half as drink, either in the form of pure water, or in that of tea, coffee, milk, or other fluids. Beside this, however, the different kinds of solid food, such as bread,

meat, etc., all contain water as part of their substance; so that, counting all that is taken in both solid and liquid food, we find that the entire quantity of water consumed every day by a healthy adult is not less than about four pounds and a half.

After being once introduced into the body and absorbed by the tissues, the water is again discharged; for its usefulness in the animal frame, like that of the other ingredients of the body, is not permanent, but temporary. It does its work while passing through the animal organism; and, having accomplished this purpose, it then makes its exit by various ways. A large proportion is discharged with the perspiration by the skin; another quantity is exhaled from the lungs with the breath; while the remainder is discharged by the kidneys.

Another inorganic ingredient of the food is common *Salt.* This substance exists in all parts of the body, though usually in much less abundance than the water; and the animal frame, therefore, could not be properly nourished without it. It is found in the different solids and fluids in the following proportions:

Quantity of Common Salt in 1000 parts in the

Muscles	2	Saliva	1.5
Bones	2.5	Bile	3.5
Cartilages	2.8	Blood	4.5
Milk	1	Mucus	6

In the blood it is more abundant than all the other inorganic ingredients excepting water.

Salt, accordingly, is not only a natural ingredient in most kinds of food, but we almost always take it in addition, as a condiment, to increase the relish of many articles of diet. This desire for salt is instinctive, and in-

dicates the natural craving of the system for something which is essential to its organization. In many instances it must be given also to the lower animals, in order to provide fully for their nourishment. Farmers and stock-breeders, for this reason, habitually give it to horses, cattle, and sheep; and experience has shown that animals, when regularly supplied with a proper allowance of salt, are kept in much better condition than when they are fed only with hay, grain, and other vegetable substances.

Salt is also useful by exciting the action of the digestive secretions, and assisting in this way the solution of the food; for food which is tasteless, however nutritious its qualities may be, is taken with reluctance and digested with difficulty; while the attractive flavor which is developed by cooking, and by the addition of salt and other proper condiments, excites the secretion of the saliva and the gastric juice, and therefore facilitates digestion. The salt, introduced in this manner, is afterward absorbed by the blood-vessels from the intestine, and is deposited in the different tissues of the body. It is finally discharged in the mucus, perspiration, and other secreted fluids.

The most important mineral ingredient of the food, next to common salt, is *Lime.* We have already seen how abundant this substance is in the bones. It is also found in still larger quantity in the teeth. It exists beside, in smaller proportions, in all the other tissues and fluids of the body. It occurs principally in the form of two different combinations, called "phosphate of lime" and "carbonate of lime." The first of these is usually the most abundant. Its proportion is shown in the following list:

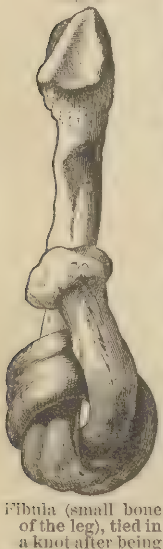
C

QUANTITY OF PHOSPHATE OF LIME IN 1000 PARTS IN THE

Teeth	650	Muscles	2.5
Bones	550	Blood	0.3
Cartilages	40	Gastric juice	0.4

In the blood, secretions, etc., the lime is in the liquid form, being dissolved by the watery parts of the animal fluids. In the bones, teeth, cartilages, and other firm tissues, it is solid, and intimately united with the animal matters of these parts. It is useful here by giving to the tissues their proper consistence and solidity. In the enamel of the teeth, which is almost entirely composed of phosphate and carbonate of lime, we have a substance capable of grinding down by mastication all the harder materials of the food, and of resisting unharmed the greatest amount of mechanical friction. In the remaining portion of the teeth, or "ivory," the lime is in smaller proportion, but still very abundant; and in the bones it continues to form more than one half the entire substance of the tissue.

Fig. 8.



Fibula (small bone of the leg), tied in a knot after being macerated in a dilute acid.

Its importance in communicating to the bones their natural stiffness and consistency may easily be seen from the effect produced by its removal. If any one of the long bones be soaked for a considerable time in a mixture of water and muriatic acid, the lime will be dissolved out, and the bone, which thus loses its rigidity, may then be bent or twisted in any direction without breaking (Fig. 8). If the bones of the skeleton, therefore, were destitute of mineral ingredients, they would bend

under the action of the muscles, and would be entirely incapable of sustaining the weight of the body.

Lime is contained, in sufficient quantity, in various kinds of food, particularly in muscular flesh, in milk, and in the vegetable grains.

The other inorganic substances existing in the food are combinations of *Soda*, *Potash*, *Magnesia*, and *Iron*. They are in much smaller quantity than those already mentioned, but serve by their presence, though in minute proportion, to complete the constitution of the food, and provide for all the mineral ingredients necessary to the formation of the tissues.

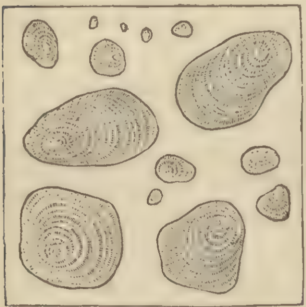
The inorganic substances, as a general rule, do not undergo any chemical change or decomposition in the interior of the body. They are absorbed with the food, and form, for a time, a part of the animal tissues; after which they are again discharged with the secretions, and replaced, in turn, by a fresh supply of similar materials. Nevertheless, they are absolutely indispensable to the proper nourishment of the body; and if the food were entirely deprived of mineral ingredients, the system would soon become seriously disordered and weakened by their absence.

15. **Starch.** — The next important ingredient of the food is *Starch*.

This substance is familiar to all in the form of a light white powder, which is used for various purposes in the arts and in manufactures. When it is rubbed between the fingers it gives a peculiar crackling sensation to the touch, by which it can almost always be recognized. But it is much more certainly distinguished by its appearance when examined under the microscope. It is then seen to be composed of minute solid grains, which

are too small to be seen by the naked eye, but which have a very peculiar appearance when magnified. Different kinds of starch can be distinguished from each other by the size and aspect of their grains. In potato starch, for example (Fig. 9), the grains vary in size from $\frac{1}{10000}$ to $\frac{1}{400}$ of an inch in diameter. They are irregularly pear-shaped in form, and are marked by fine concentric lines, as if the substance of the starch-grain had been deposited in layers. At one spot on the surface of each there is a minute point, and the circular lines are arranged round this point as a centre.

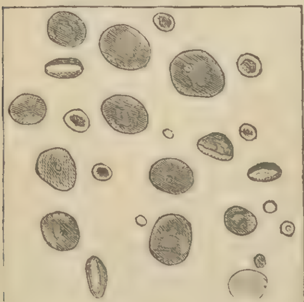
Fig. 9.



Grains of Potato Starch.

In wheat starch (Fig. 10) the grains are not so large as in that from the potato. They vary from $\frac{1}{10000}$ to $\frac{1}{700}$ of an inch in diameter. They are also nearly circular in shape, but do not show any distinct concentric lines. Many of them are compressed or flattened from side to side, so that they present a broad surface in one direction, and a narrow edge in the other.

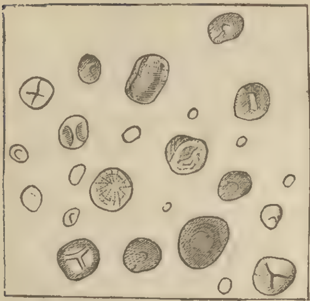
Fig. 10.



Starch grains of Wheat flour.

The starch grains of Indian corn (Fig. 11) are of nearly the same size with those of wheat flour; but they are usually more angular and irregular in form,

Fig. 11.



Starch grains of Indian corn.

and are often marked with crossing or radiating lines, as if they had been partially broken by pressure.

Now all the starch which is used for food, for the arts, or in manufactures, is obtained from plants. It is not an inorganic substance, therefore, like water, salt, or lime, but is a product of vegetable growth. Its minute grains are found packed away in the tissues of the plants, among their fibres, and in the interior of vegetable cells; and are accumulated in various quantities in their tuberous roots, in the pith of their stems, or in their seeds and fruit. It forms at least one seventh of the whole substance of the potato, about one third of peas and beans, over one half of wheat, rye, and oats, and at least three quarters of rice and Indian corn. Arrow-root is nothing but the starch from the tuberous roots of a West Indian plant; Tapioca is starch from the root of another plant, also from the West Indies; and Sago is nearly pure starch from the pith of various kinds of palms.

The exact quantity of starch in the more ordinary articles of food is shown in the following list:

QUANTITY OF STARCH IN 100 PARTS IN

Rice	85.07	Wheat flour	72.00
Maize	80.92	Iceland moss	44.60
Barley-meal	67.18	Kidney-bean	35.94
Ryemeal	61.07	Peas	32.45
Oatmeal	59.00	Potato	15.70

It is obtained in a pure form by grinding up some

vegetable matter which contains it in abundance, and mixing it with cold water. The water is then strained and allowed to stand, when the starch after a time settles to the bottom, and is finally dried and powdered.

Starch is not affected by cold water; but if it be boiled for a short time, its grains swell up, become transparent, absorb a large quantity of water, and at last melt away into a thin, grayish-looking fluid. When this fluid is allowed to cool, it sets or stiffens into a kind of pasty mass, which is quite solid if the starch have been used in large quantity. But after this cooking process the separate grains are no longer to be distinguished, and the whole is changed into a uniform homogeneous material, because the water has been permanently absorbed by the starch, and is therefore retained in combination with its substance.

Another very curious fact about starch is that by various means it may be entirely altered in its qualities and converted into sugar.

One mode of accomplishing this singular transformation is the following: If starch be mingled with a very thin watery solution containing an acid, and boiled for a short time, it soon loses its grayish color, and becomes quite clear and transparent; and if the boiling be continued for a longer period, all the starch finally disappears, and the solution is then found to have a sweet taste and to contain sugar. The starch, in fact, has been consumed or altered, and sugar has taken its place.

Some animal and vegetable substances have the power of causing the same change. Thus, if a little saliva from the mouth be mixed with a solution of starch and then kept in a warm place, after a time the starch will be found to have disappeared and sugar to have been

produced instead. Something of this kind happens in certain vegetable tissues, especially in seeds during the first process of their growth or "germination," when a part of the starch which has been stored up in their substance becomes changed spontaneously into sugar.

We shall also find hereafter that the starch which is taken with the food is entirely changed in the process of digestion. None of it, therefore, is to be found afterward in any of the circulating fluids or secretions of the body.

16. **Sugar.**—The next ingredient of the food is *Sugar*, which, as we have already seen, is closely related to starch. Sugar is always readily distinguished by its sweet taste, a character which forms its most attractive quality. It is found in many animal and vegetable juices, being obtained principally from the juices of the sugar-cane, the rock maple, and the beet root; but of these, the sugar-cane supplies much the largest quantity. In its natural condition the sugar is dissolved in the vegetable fluids, where it is mingled with many other different substances.

It is extracted in the following manner:

The vegetable juices are first collected by crushing the fresh sugar-canes between iron rollers. The fluids obtained in this way are then heated with a solution of lime, which causes many of their impurities to separate and rise in a kind of scum upon the surface. This is carefully removed, and the purified juice is then boiled down until the sugar solidifies as a brownish colored granular deposit. This brown sugar is again dissolved and farther separated from its impurities by boiling and crystallizing, until it is at last obtained in a pure, white, granular crystalline mass.

Beet-root sugar, which is manufactured very extensively in France, is prepared from the juices of the beet by a similar process to that just described, and is very pure, white, and crystalline in appearance.

Maple sugar is prepared from the sap of the maple-tree, which runs freely, in the early part of the spring, from punctures made in the wood, and which is afterward boiled down until the sugar solidifies. This sugar, however, can not be completely purified, and therefore remains comparatively moist and brownish in color.

Molasses is the sweet residue of the vegetable juices which can not be crystallized, and which also contains, mingled with it, various flavoring and coloring matters, which impart to it a peculiar taste.

Sugar also exists in considerable quantity in milk, in honey, and in all the sweetly-flavored fruits and vegetables, such as apples, pears, grapes, corn, flour, etc. The following list shows the quantity which is contained in various articles of food:

QUANTITY OF SUGAR IN 100 PARTS IN

Figs	62.50	Wheat flour	5.40
Cherries	18.12	Ryemeal	3.28
Peaches	16.48	Indian-meal	1.45
Tamarinds	12.50	Peas	2.00
Pears	11.52	Cow's milk	4.77
Beets	9.00	Ass's milk	6.08
Sweet almonds	6.00	Human milk	6.50

One of the most remarkable properties of sugar is that it is capable of being decomposed in a peculiar manner, and converted into other substances by *Fermentation.* Fermentation sometimes takes place spontaneously, in warm weather, in molasses, honey, and other liquids containing sugar; when they swell up, be-

come frothy, and acquire a different taste and odor. It is also produced artificially for the purpose of manufacturing wines and spirituous liquors. This process will be more fully explained hereafter.

The sugar which is taken with the food is destroyed, like starch, in the interior of the body, and, excepting that contained in the milk, is never discharged during health with the secreted fluids.

17. **Fats, or Oleaginous Substances.**—The food also contains a considerable quantity of *Fats* or *Oleaginous substances*. The fats are obtained from both animal and vegetable tissues. They are exceedingly valuable, not only as articles of food, but also for frequent use in the arts and manufactures.

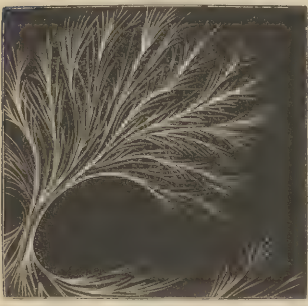
We can readily distinguish fats and oleaginous matters by their appearance to the eye, by their unctuous feel, and especially by their "lubricating" property, on account of which they are extensively used to facilitate the action of machinery, and prevent its being injured by friction. Now if any of these fats or oils be closely examined, they are usually found to contain, mingled together, three different oleaginous substances, which are known by the names of *Stearine*, *Margarine*, and *Oleine*. These substances resemble each other very closely in most respects, but are principally distinguished by their consistency. Stearine is the most solid substance of the three, margarine rather less so, and oleine is the most fluid. In their natural condition they are usually mingled with each other in the animal and vegetable tissues in different quantities. When the mixture contains a larger proportion of stearine or margarine, it is more firm in consistency, like the various kinds of "fat," such as lard, tallow, wax, butter, etc.; and

when it contains a greater abundance of oleine it is more liquid, and we therefore call it an "oil."

But when these substances are completely separated from each other and purified, the difference in their consistency is very marked. Thus stearine is often made up by itself into candles, and remains perfectly solid until melted by the heat of the burning wick. On the other hand, olive oil, which consists mostly of oleine, is quite liquid at all ordinary temperatures.

Generally speaking, however, these mixtures of the oleaginous substances in the human body are fluid, or nearly so, during life; for the margarine and stearine which they contain are dissolved in the oleine by the warmth of the living body. But after death, when the body cools, the stearine and margarine sometimes separate from the mixture in a crystalline form, since the oleine can no longer retain in solution so large a quantity as it had dissolved while warm.

Fig. 12.

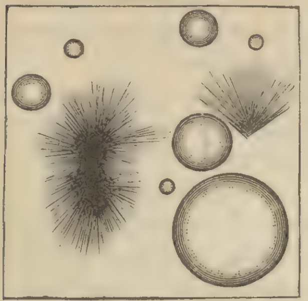


Stearine crystallized from a warm solution in oleine; magnified.

The oleaginous substances crystallize in very slender needles, which are always more or less radiated, sometimes straight, and sometimes curved and wavy in their outline. They frequently have a very elegantly branched or arborescent arrangement (Fig. 12).

When they are in a fluid state, the oleaginous matters show themselves under the form of rounded drops or globules, which vary exceedingly in size, but which may be easily recognized by

Fig. 13.



Oleaginous principles of human fat. Stearine and margarine crystallized; oleine fluid.

their appearance under the microscope. They have a faint amber color, and a very sharp, well-defined outline, showing a brilliant centre surrounded by a dark border. In Figure 13 these fluid oil-drops are seen mingled with radiating crystals of the more solid fat.

One of the most important characters of oil, and of all oleaginous matters, is that they will not dissolve in water, nor remain in any way intimately mingled with it, so that it is even proverbial that "oil and water will not mix." For if the two liquids be violently shaken up together in a bottle so as to mingle them as thoroughly as possible by mechanical agitation, as soon as the mixture is allowed to remain at rest the oil at once begins to separate from the water, and, being lighter, rises to the surface; and after a short time all the oil will be collected by itself at the top, and all the water will remain by itself at the bottom. So strong is the repulsion between these two liquids in their natural condition.

But it is very different when certain other substances are added at the same time; for if some alkaline substance, such as potash or soda, be first dissolved in the water, and the oil then gently shaken up with it, it immediately becomes separated into very fine particles, and uniformly disseminated through the whole mixture. The oil is no longer liable to separate from the watery parts, even when left at rest, but the whole re-

mains as a uniform, white, opaque, milky-looking fluid. Such a mixture of oily granules uniformly suspended in a watery liquid is termed an *Emulsion*.

The same effect may be produced by some of the animal matters; for if we take a fresh white of egg in its fluid condition, and shake it up thoroughly with a little oil, the whole becomes white and turbid, and remains permanently in the state of an emulsion. This property is often found useful in reducing oily substances to a state of minute subdivision.

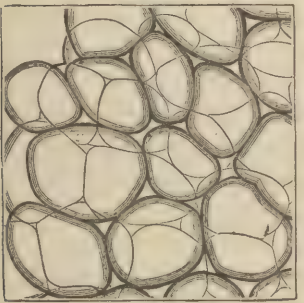
The oleaginous matters exist in the animal and vegetable tissues under a peculiar form. For while they are always mutually dissolved and united with each other, as we have already seen, they do not dissolve in water, nor do they combine with other substances, such as salt, starch, or sugar. On the contrary, they are deposited separately in drops and granules in the interstices of the fibres, or in little cavities which are intended for their reception. Even in the animal fluids and secretions, such as milk, they are not dissolved in the watery parts, but are suspended in them in the condition of minute granules, forming an emulsion, as above described.

Owing to this fact, the oils can be easily extracted from the organized tissues, for the most part, by simple mechanical means. The animal or vegetable tissues containing them are merely cut into small pieces, and then subjected to pressure, by which the oil is forced out from the parts in which it was entangled, and collected in a state of purity. Sometimes the operation is assisted by heating the substances, and thus making the oily matters more liquid; and sometimes they are boiled with water, when the oils rise to the top, and may be skimmed off by themselves. No chemical change or

decomposition, therefore, is required, but the oils are simply separated mechanically from the parts with which they were naturally entangled.

The tissue in which the oleaginous matters are most abundantly found in the animal body is called the "Fat," or the "Adipose tissue." It consists of a great number of little sacs or vesicles, each one composed of a thin transparent membrane forming a closed cavity, in which the oily matter is contained (Fig. 14). These vesicles are associated together into masses or lobules, surrounded by cellular tissue, and supplied with blood-vessels and nerves.

Fig. 14.



Human adipose tissue.

Neither the blood-vessels nor the nerves, however, are very abundant; so that the adipose tissue is not very sensitive, nor does it bleed freely when wounded. It acts as a soft and delicate cushion, placed underneath the skin to protect the neighboring parts from injury; and it also serves to retain the warmth of the internal organs, and prevents its being too rapidly dissipated. Consequently, those persons who are well provided with fat are much less readily chilled by exposure to cold than those who are thin and emaciated.

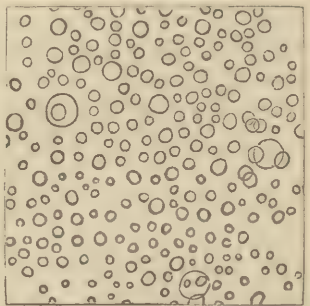
In some of the internal organs oily matters are deposited in their tissue in the form of drops and globules. Thus, in the glandular cells of the liver (Fig. 15), oil is always found in more or less abundance, forming a natural part of their constitution. It is also found in the cartilages of the ribs, and in some other situa-

tions; but always in separate globules and granules, which may readily be distinguished by their appearance under the microscope.

Fig. 15.

Glandular cells of the liver, containing oil globules; magnified.

Fig. 16.



Milk globules, as seen under the microscope.

In the milk, which is a kind of natural emulsion, the oily matters also exist in the form of little masses or globules, called the "milk globules" (Fig. 16). They constitute the *Butter* of the milk, which, in its natural condition, is suspended in the watery liquid, and gives it its white and opaque appearance. By churning, these globules may be separated from the other ingredients of the milk, and collected into a uniform mass.

Oleaginous matters are taken in large quantity with the food, mostly in butter, in milk, in the fat of meat, and in some vegetable substances, such as olive oil, etc. The following list shows the proportion of oily matters in various kinds of food:

Quantity of Fat in 100 parts in

Filberts	60.00	Ordinary meat	14.30
Cocoanuts	47.00	Liver of the ox	3.89
Olives	32.00	Cow's milk	3.13
Yolk of eggs	28.00	Human milk	3.55
Indian corn	9.00	Goat's milk	3.32

The fat which is taken with the food disappears for the most part in the interior of the body, like starch and sugar. A very little is secreted by certain glands in the skin and about the roots of the hair, which serves to keep these parts soft and pliable. But this forms only a small portion of the whole; the greater part of the oleaginous matters, except what is stored away in the adipose tissue, being used up and consumed for the nutrition of the body.

18. **Albuminous Matters.**—The last class of substances contained in the food are the *Albuminous matters.* These substances are peculiar in many respects, and very important; for of all the solid ingredients of the body, they constitute considerably the largest part of its mass. They are not composed of grains, like starch, nor are they ever crystalline in form, like sugar and fat; but, even when solid, they are smooth and uniform in texture. They have also a peculiar consistency, which combines in a remarkable degree the two qualities of softness and solidity. We may form an idea of this peculiar consistency by feeling of any of the internal organs, such as the liver or heart of an ox, or a piece of muscular flesh. These organs are firm enough to retain their form and texture, and yet they are soft to the touch. They have these qualities because they are composed in so large a proportion of the albuminous matters.

The albuminous matters are derived both from animal and vegetable sources, but they are most abundant, as a general rule, in animal substances. It is for this reason that animal food is, for the most part, richer and more nutritious than that which is composed of vegetables.

The albuminous matters are of various kinds, some of them being liquid in their natural condition, some of them solid, and some of them having a consistency intermediate between the two. That which is most familiar to us, and which has given its name to the whole class, is *Albumen*, which is the principal ingredient in the white of egg. Another kind of albumen is also found in the blood, and is the most abundant of its animal ingredients. *Fibrine* is also found in the blood, though in smaller quantity than albumen. *Caseine* is the albuminous substance of milk, and when solidified forms the principal ingredient of cheese. *Gluten* is the albuminous matter of wheat flour, and is an important element in the making of bread.

There are other albuminous substances found in various kinds of food and the different parts of the body; but those which we have already mentioned are the most familiarly known, and will serve to represent the peculiarities of the entire class.

One of these peculiarities is the property of *Coagulation.* The albuminous matters which are naturally liquid may be suddenly solidified in various ways, after which they are said to be "coagulated." Some of them may be coagulated by one method, others by a different one; and we may often distinguish one albuminous substance from another by the particular method required for its coagulation.

Thus white of egg, in its natural state, is transparent, of a light amber color, and very nearly liquid; but if it be heated to the temperature of boiling water, it coagulates, and becomes solid, white, and opaque.

Milk, on the other hand, may be boiled without coagulating; but if a little acid be added to it, such as vin-

egar or lemon-juice, its caseine at once solidifies, and it assumes the coagulated form.

The fibrine of the blood, again, coagulates without either boiling or the addition of an acid. If a little blood be drawn from the veins and received into a cup, it becomes clotted in a few moments by a spontaneous change which takes place in its own substance.

Nothing similar to this property of coagulation belongs to any other than the albuminous substances.

Another peculiarity of the albuminous matters is that they become *Ferments*. This property is so important that it will require a particular description. A "ferment" is a material which, on being added in small quantity to other substances, causes in them a remarkable change and decomposition, often accompanied by the production of bubbles of gas and the formation of entirely new ingredients. This change is called "fermentation." Thus, if a little yeast be added to a mixture of flour and water, and the whole kept in a warm place, the influence of the yeast disseminates itself throughout the whole, and causes the entire mass to ferment. If milk be allowed to remain two or three days in a warm place, the caseine is partially altered, and then becomes a ferment, which changes the sugar of the milk into an acid substance called "lactic acid;" when the acid thus produced reacts upon the rest of the caseine and coagulates it, as any other acid would do. This is the manner in which the ordinary souring and curdling of milk takes place. The souring of the milk is caused by the change or decomposition of the sugar of the milk, and the curdling or coagulation is caused by its acidity.

Now a "ferment" is always composed of an albumi-

nous substance. This substance may not be perfectly fresh; indeed, it is very often the case that the ferments most in use are albuminous matters which are themselves beginning to suffer decomposition. But when the ferment is introduced, in ever so small a quantity, into another mixture, it seems to act by contagion, and excites by its mere presence an extensive change, which often pervades the entire mass.

A ferment always requires for its action two things: first, the presence of moisture; and, secondly, a moderately warm temperature, between the two extremes of heat and cold. None of the ferments, therefore, will act if they are perfectly dry, and they are also inactive so long as they are kept at a freezing temperature; but if supplied with moisture, they begin to act when the temperature rises, and become more energetic as the warmth increases. Their activity is usually greatest about the temperature of the living body, or 100 degrees Fahrenheit. Above this point they again become less active, and cease altogether when the temperature approaches that of boiling water.

Lastly, the albuminous matters are the only ones liable to *Putrefaction.* This is a peculiar kind of decomposition, which resembles, in many respects, that of fermentation. For example, one substance which is already partially decomposed will excite putrefaction in others of the same kind more quickly than if they were left to themselves; and decayed fruit, as it is well known, will rapidly contaminate sound fruit of the same kind, if left in contact with it. But still all substances of an albuminous nature, if exposed to the air and moisture at warm temperatures, will after a time become putrefied; that is, they decompose and liquefy,

with the production of a variety of gases, of a peculiarly disagreeable odor, which are called "putrefactive gases." Thus, whenever we perceive the odor of putrefaction, we know that some substance composed of albuminous matter is undergoing decomposition.

Like fermentation, putrefaction will not take place without moisture; for meat or vegetable matters, if thoroughly dried, will keep unchanged for an indefinite period. Neither will it go on at a low temperature; and dead substances kept at the freezing point will not putrefy. The most complete preservation takes place when the two conditions of cold and dryness are combined. At the Hospice of the Great St. Bernard, in Switzerland, a little over 8000 feet above the level of the sea, the bodies of travelers found frozen in the snow are sometimes preserved for over twenty years. For, while still at a freezing temperature, they become thoroughly dried; and though after a long time they slowly crumble and become disintegrated, there is no putrefaction, nor any evolution of putrefactive gases.

Finally, animal substances are also incapable of putrefaction at a very high temperature. Meat which has once been boiled changes much less rapidly than if exposed to the air when fresh; and if kept at the temperature of 200 or 300 degrees Fahrenheit, either dries up altogether, or suffers a change entirely different from putrefaction.

The following list shows the proportion of albuminous matter in various kinds of food:

Quantity of Albuminous Matter in 100 parts in

Muscular flesh	22.00	Wheat flour	7.30
White of egg	15.28	Oatmeal	4.30
Yolk of egg	12.75	Milk	4.48

Albuminous matters, like starch, sugar, and oil, are almost entirely consumed and altered in the process of nutrition, only a small portion of them being discharged with the perspiration and other secreted fluids. By far the greater part disappears in the interior of the body.

19. **Necessity for all these Substances in the Food.**—From what has already been said, it will easily be understood that the food *must contain, in some form or other, all the different classes of substances above enumerated.* Food, from which either one of the substances necessary to nutrition is absent, although it may be nutritious for a time, will certainly fail, sooner or later, to keep up the proper organization of the body, and its deficiency will be inevitably felt. This is true even of the inorganic substances. A man might be starved to death by keeping him on food which contains no lime or no salt; that is, after a time he would become so feeble that slight causes would be sufficient to produce a fatal result. This would not happen so soon as if he were deprived of the more nutritious matters, because they are required in larger quantity. But it would certainly take place at last; for the mineral ingredients of the body, though small in amount, are still indispensable to health. We have already seen that they are usually present in sufficient quantity in the substances used as food.

Neither will any of the proper ingredients of the food be sufficient by themselves. The experiment has been tried of feeding animals upon food containing only starch and sugar; and although such food is consumed with relish for a time, the animals soon become feeble and emaciated, and finally die of imperfect nutrition. In some instances this experiment has been tried by

medical men upon themselves, who have always found their health to suffer after a few days of such diet, and who have never been able to continue it indefinitely, owing to increasing debility and general disturbance of the system.

A diet exclusively composed of fatty substances is equally incapable of supporting life. This has been tried at various times on quadrupeds and birds; and it has been found that after a short time, usually about three weeks, these animals, though abundantly fed with fat, die with all the symptoms of inanition.

Lastly, the same thing is true even of the albuminous matters. These substances are usually considered more nutritious than the others. But this is only because they are required in greater quantity than the rest, since they form so large a proportion of the animal tissues. The albuminous matters, if taken alone, are no more capable of supporting life indefinitely than starch, sugar, or oil; and animals, when fed on pure fibrine or pure albumen, become emaciated and at last die of inanition, as in the cases mentioned above.

All these substances, therefore, must be combined, in order to make the food which contains them capable of sustaining life.

Now it is found that every article of food which has been universally recognized by the instinct of man as especially valuable, does in reality contain these different ingredients, viz., 1st, water and mineral substances; 2d, oleaginous or starchy materials, or both; and, 3d, some form of albuminous matter. This will be distinctly shown when we come to examine more particularly the different kinds of alimentary substances.

QUESTIONS FOR CHAPTER II.

1. What is the definition of "food?"

2. What is the food intended to supply?

3. What are the "inorganic substances?"

4. Which is the most abundant of the inorganic ingredients of the food?

5. What parts of the body contain *water?*

6. What is the use of water in the animal fluids? In the solids?

7. What proportion of the whole body consists of water?

8. How much water is consumed per day by a healthy adult?

9. Does the water remain in the body, or is it again discharged from the system?

10. By what channels is the water discharged from the body?

11. What is the next most important inorganic ingredient?

12. In what animal fluid is *salt* most abundant?

13. Why is salt useful as an article of food?

14. In what organs of the body is *lime* most abundant?

15. What effect is produced on the bones by depriving them of their lime?

16. In what articles of food is lime contained?

17. What are the other inorganic ingredients of the body and the food?

18. Are they decomposed in the body, or discharged with the secretions?

19. What is the physical appearance of *starch?*

20. From what sources is it obtained?

21. What kinds of food contain the largest quantities of starch?

22. What is the mode of obtaining starch from vegetables?

23. What is the effect of boiling starch with water?

24. Is starch discharged again with the secretions, or decomposed within the body?

25. How may starch be converted into *sugar?*

26. What is the characteristic property of sugar?

27. From what sources is sugar obtained?

28. What is the process of extracting sugar from cane-juice? From the beet-root? From the maple-tree?

29. What is *molasses?*

30. What other articles of food contain sugar?

31. Is the sugar discharged with the secretions, or decomposed within the body?

32. How are the *fats* or *oleaginous substances* distinguished?
33. What are the three varieties of fats?
34. How do they differ from each other?
35. What is the appearance of their crystals?
36. What is the appearance of fluid oil-drops?
37. Can oil be dissolved in water?
38. What happens if you shake up oil and water together?
39. What is an *emulsion?*
40. What substances will convert oil into an emulsion?
41. How do the fats exist in the interior of the body? United with the other ingredients, or separate?
42. How can fats be extracted from animal and vegetable tissues?
43. In what tissues of the body are the oleaginous matters most abundant?
44. What is the structure of fat, or adipose tissue?
45. What is its use in the animal body?
46. What is the appearance of the oleaginous matters in milk?
47. What other kinds of food contain fat?
48. Is fat discharged with the secretions, or decomposed within the body?
49. What is the last class of ingredients of the body and the food?
50. What is the peculiar consistency of the albuminous matters?
51. Are the albuminous matters more abundant in animal or in vegetable food?
52. What are the four principal kinds of albuminous matters, and where are they found?
53. What is the process of coagulation?
54. How can albumen be coagulated? How caseine? How fibrine?
55. What is a *ferment?*
56. What is the process of the souring of milk?
57. At what temperature does fermentation take place?
58. What is putrefaction?
59. Is putrefaction communicated from one substance to another?
60. How may putrefaction be prevented?
61. What kinds of food contain the greatest abundance of albuminous matters?
62. Are the albuminous matters discharged from the body, or decomposed in the animal system?
63. Can life be sustained upon starch or sugar alone? Upon fat alone? Upon albuminous matter alone?
64. Does the natural food contain all these different ingredients?

CHAPTER III.

THE DIFFERENT KINDS OF FOOD, AND THEIR MODE OF PREPARATION.

Meat—its Composition.—Effect of Cooking.—Eggs.—Composition of the White and Yolk.—Milk—its Composition.—Butter—how obtained. — Cheese — its Preparation. — Bread — how made. — Yeast.—Fermentation of Bread.—Baking.—Wine—its Fermentation.—Beer.—Vegetables.—Effect of Cooking on Vegetables.—Essential Qualities of Food.—Necessary Quantity.

20. **Meat.**—Meat consists of the muscular flesh of various animals, mingled with more or less of fat or adipose tissue. Of all the different varieties, beef is undoubtedly the most valuable and the most extensively used. Mutton and venison hold the next place; then the flesh of fowls, the various kinds of game birds, and, lastly, fish.

In ordinary meat we have the albuminous substance of the muscular fibres and cellular tissue, and the oleaginous matter of the fat, in about the following proportions:

COMPOSITION OF ORDINARY BUTCHER'S MEAT.

Muscular parts	85.70	Water	63.42
		Solid matter	22.28
Fat, cellular tissue, etc.			14.30
			100.00

The preparation of meat for food consists in exposing it to a high temperature, usually by roasting or boiling. In roasting, the meat is simply cooked in its own juices; in boiling, it is cooked by the aid of the boiling water. The effect of the heat thus applied is as follows:

First, the albumen which is present in the muscular tissue is coagulated, and the muscular fibres therefore become rather firmer and more consistent than in the fresh meat.

Secondly, the cellular tissue between the muscular fibres is softened and gelatinized, so that the fibres are more easily separated from each other, and the whole mass becomes more tender and easily digestible; and, thirdly, the high temperature develops in the albuminous ingredients of the meat a peculiar and attractive flavor, which they did not possess before, and which excites in a healthy manner the digestive secretions, thus serving not only to please the taste, but also to assist in the digestion of the food. Raw meat, accordingly, is usually insipid and unattractive. It is only after it has been subjected to a certain amount of cooking that the desired flavor makes its appearance, by which the appetite is stimulated, and the nutritious qualities of the food consequently improved.

The preparation of meat in cooking should be carefully managed, so as to accomplish the results above described. For if the heat be insufficient, the proper flavor will not be developed; and if it be excessive, the meat, instead of being cooked, will be burned and decomposed, and thus rendered useless for the purposes of nutrition.

21. **Eggs.**—Eggs consist of the "white," which is almost entirely composed of albumen and mineral ingredients; and the "yolk," in which a large proportion of oleaginous substance in a granular form is mingled with the albuminous matter, giving it an opaque yellow color. The exact composition of the two parts is as follows:

COMPOSITION OF EGGS.

	White of Egg.	Yolk of Egg.
Water	80.00	53.78
Albumen and mucus	15.28	12.75
Yellow oil	—	28.75
Salts	4.72	4.72
	100.00	100.00

When eggs are boiled or otherwise cooked, the albumen, of course, is coagulated, and becomes white and opaque. The yolk also becomes firmer than before, but still remains less solid than the white, owing to the large proportion of oily matter mingled with it.

22. **Milk.**—Milk, which is the first food of the infant, represents more fully than any other single substance a complete collection of all the alimentary materials. It contains water; a full supply of mineral ingredients; caseine, which is its albuminous substance; the milk globules, which are oleaginous, and held in suspension; and sugar, which is dissolved in the watery parts. The proportion of these substances is as follows:

COMPOSITION OF COWS' MILK.

Water	87.02	Sugar of Milk	4.77
Caseine	4.48	Mineral ingredients	0.60
Butter	3.13		100.00

The *Butter* of the milk, as we have already seen, is in the form of minute globules. The whole mixture is an "emulsion," in which the oleaginous matter is held in suspension, and disseminated through the watery fluid by the action of the albuminous caseine. The milk globules are not perfectly fluid like oil, but have a pasty or semi-solid consistency. Accordingly, they can be collected and separated from the other ingredients in the form of butter.

For this purpose the fresh milk is placed in shallow pans, and allowed to remain undisturbed for twenty-four hours. During this time the surplus quantity of the milk globules rise to the top, owing to their being lighter than the watery parts, and collect in a thick, densely white layer upon the surface. This upper layer of fluid, which is richer than the rest in milk globules, is the "cream." When a sufficient quantity of cream has been collected, it is removed and placed in churns, where it is subjected to continuous beating with wooden ladles. By this process the milk globules are beaten together and made to cohere into a uniform, consistent, yellowish mass. This mass is the butter.

The butter, however, when obtained in this way, still retains entangled with it some of the watery portions of the milk containing caseine, sugar, etc., in solution. These must be carefully removed; for if the caseine be allowed to remain, it soon begins to be altered, acts as a ferment, and then produces a change in the butter by which it becomes rancid. To guard against this, the butter is thoroughly worked over, and the liquid impurities washed out or absorbed by appropriate means, until they are entirely removed.

When the butter is completely purified in this way, it has the following composition:

COMPOSITION OF THE BUTTER OF COWS' MILK.

Margarine	68
Oleine	30
Butyrine	2
	100

The last of these ingredients, the "butyrine," is the substance which gives to the butter of cows' milk its peculiar flavor.

Cheese is composed principally of the solidified albuminous matter of the milk, or "caseine." Caseine, as we have seen, may be coagulated by any acid substance; but the material usually employed for this purpose is derived from the fourth stomach of the calf. The juices of this stomach contain a substance which will be more fully described hereafter, and which has the property of coagulating milk in a very gentle and uniform manner. When the calf has been fed with milk, the stomach is taken out, cut into strips, and dried for future use. The whole mass thus contains the coagulating principle disseminated through its substance, and is then called "rennet."

When a little rennet, previously softened in water, is added to fresh milk, it produces a coagulation of its caseine. The coagulated mass is then subjected to strong pressure, by which the watery parts of the milk are driven out, and the whole reduced to the consistency of cheese. A considerable portion of the butter of the milk still remains entangled with the caseine, and communicates to it a rich flavor and a yellowish color. The very gradual change which the caseine undergoes on exposure to the air produces also a certain alteration in the buttery ingredients, by which the cheese, after being kept for a time, usually assumes a sharper and rather aromatic flavor. Cheese accordingly contains the nutritious elements of the milk in a condensed but somewhat indigestible form.

23. **Bread.**—Bread is made of various kinds of grain, but by far the best and most nutritious is that made from wheat. Wheat flour contains the following ingredients;

Composition of Wheat Flour.

Gluten	7.30	Gum	3.30
Starch	72.00	Water	12.00
Sugar	5.40		100.00

In the making of bread, the flour is first thoroughly mixed with water and worked up into a pasty mass, to which is then added a little *yeast.*

Fig. 17.

Vegetable fungus of yeast; magnified.

Yeast consists of an albuminous matter containing an abundance of a fungous vegetable growth, in the form of minute globules or cells (Fig. 17), which rapidly multiply by a process of budding whenever placed in a favorable condition. It is one of the most energetic kinds of ferment, and is especially liable to act upon all substances containing sugar.

The mixture of flour and water, with the yeast added, is then placed in a warm temperature, and allowed to remain for some hours. During this time the yeast excites a fermentation, by which the sugar of the flour is decomposed, and converted into alcohol and carbonic acid. The carbonic acid is a gas; and, being produced in the form of small air-bubbles, attempts to rise and escape from the dough, just as it would from a watery mixture. But the gluten of the wheat, being somewhat viscid in consistency, entangles and retains the bubbles of gas as they are developed in its substance, and the whole mass of the dough is thus distended and puffed up by the gaseous matter contained within it.

The dough, thus distended, is then baked at a high temperature. The effect of this is to fix and solidify the gluten, and cause it to retain the form which it has already assumed. When the baked loaf, accordingly, is afterward cut through, it is seen to be every where perforated with a multitude of little cavities, which were formerly occupied by the gas developed in fermentation. This gives the bread a light and honey-combed or spongy texture throughout the interior of its mass.

It is this spongy texture, given to bread in the manner above described, which is the main object of the process of fermentation. For if the flour were simply mixed with water and baked, the solid and consistent mass thus produced, though abundantly nutritious, would be tough and difficult of digestion; but, owing to the light texture which it acquires in fermentation, it is afterward easily masticated, and becomes readily penetrated and acted on by the digestive fluids.

The small quantity of alcohol produced during the fermentation of bread is dissipated by the heat of the oven, and carried off by evaporation.

The starch of the flour, during this process, absorbs water under the influence of the heat, and its grains become amalgamated with each other. The whole amount of water which is absorbed and retained by the dough is rather more than twenty-five per cent. of its original weight; so that one pound of flour, after being mixed with water and made into bread, weighs a little over one pound and a quarter.

24. **Wine.**—Wine is produced from the juices of the grape after undergoing fermentation.

The juices of the ripe grape, in their natural condi-

tion, contain water, a little albuminous matter, sugar, various coloring and flavoring substances, and a small quantity of mineral ingredients. For the purpose of making wine, the juice is first expelled by crushing the grapes, and then exposed to the air in vats at a moderately warm temperature. After a short exposure, the albuminous matter suffers a certain alteration by contact with the air, and becomes a ferment; and this ferment then acts upon the sugar of the grape-juice, converting it into alcohol and carbonic acid, as in the fermentation of bread. The fermentation of the grape-juice, however, is a slow and gradual process, often requiring several months for its completion. During this time the carbonic acid gas which is produced rises to the surface in bubbles, and escapes from the fermenting liquid; but the alcohol remains behind, giving to the liquid a vinous or alcoholic taste.

When the fermentation of the wine is completed, it forms a clear and transparent liquid, containing water, alcohol, coloring matter, and various flavoring substances; some of which are derived directly from the original ingredients of the grape-juice, while others are formed from their alteration during the fermenting process.

In some wines all the sugar of the grape-juice is not completely decomposed by the process of fermentation; they therefore retain a sweet taste, in addition to the alcoholic flavor.

In some instances the wine is bottled before the fermentation is finished; and, the process continuing to go on, the carbonic acid gas afterward produced is accumulated and confined in the imprisoned liquid. When the bottles are then opened and the pressure taken off,

the superabundant gas escapes in bubbles, sometimes with considerable force. Such wines are called "sparkling," or "effervescent" wines.

The strength of any particular wine depends on the quantity of alcohol produced in its fermentation. Still, wine is not simply a mixture of alcohol and water, but it contains many other ingredients furnished by the juices of the fruit from which it is made; and the alcohol, produced by a slow fermentation, is united with various other vegetable substances also undergoing peculiar modifications.

Consequently, wine can not be artificially manufactured by mixing together alcohol, water, sugar, etc. Such a mixture is simply a crude imitation, generally hurtful in its effects, and, for the most part, wanting in the peculiar properties of the wine which it is intended to imitate.

25. **Beer.**—Beer is a liquid prepared from barley, somewhat in the same way as wine is made from grapes. We have already mentioned that in the first sprouting or "germination" of many seeds, the starch which they contain is transformed spontaneously into sugar. This happens with the grains of barley. In order to make beer, the barley is kept warm and moist until germination has taken place, and a sufficient quantity of sugar has thus been produced in their substance. The barley is then ground up, mixed with warm water, and an infusion of hops, with a little yeast, added to the mixture. The hops serve as a flavoring ingredient; and the yeast, acting as a ferment, causes the fermentation of the sugar, producing alcohol and an abundant evolution of carbonic acid gas. The liquid finally produced is beer. It contains much less alcohol than wine, but a

large proportion of flavoring and nutritious substances are also derived from the grain used in its preparation.

26. **Preparation of Vegetables.**—Of the different *Vegetables* used for food, such as potatoes, beans, peas, turnips, etc., the greater part contain principally starch, mingled with various proportions of albuminous matter, sugar, water, and mineral substances. The effect of cooking upon these vegetables is mainly to soften and disintegrate them, since in their raw state they are usually so hard as to be entirely indigestible. It is very essential, therefore, in the preparation of vegetables, that their cooking should be thorough and complete, as otherwise they are liable to produce injurious effects. An agreeable taste is also developed in vegetables by the process of cooking, though not to so great an extent as in the case of animal substances.

27. **Necessary Qualities of wholesome Food.**—In order to maintain health, the food which is consumed should be *simple*, but, at the same time, *nutritious in quality*, and *the very best of its kind.* The meat should be that of well-fed animals, of good color, and abundantly supplied with the natural juices. The bread should be made from well-ground and properly-dried flour; and the vegetables should be of natural color and consistency, and free from excrescences or other imperfections. Particularly the preparation of the food by cooking should in all cases be carefully performed; since improper cooking will often vitiate or destroy the nutritious qualities of the most valuable kinds of food.

28. **Quantity of Food required.**—The *entire quantity* of food required during twenty-four hours varies with the age, sex, and habits of the individual. Children require more food, in proportion to their size, than adults;

and those who take much physical exercise need more than those who remain comparatively inactive. As a general rule, however, it is a valuable indication of health when the full average quantity of food is required and consumed every day. The result of investigation on this point shows that for a healthy adult man, taking free exercise in the open air, and living upon plain but substantial food, the average quantity required during twenty-four hours is as follows:

AVERAGE DAILY QUANTITY OF FOOD.

Meat	16 ounces,	or 1.00 lb.	avoirdupois.
Bread	19 "	" 1.19 "	"
Butter or fat	3½ "	" 0.22 "	"
Water	52 fluid oz.	" 3.38 "	"

that is to say, rather less than two and a half pounds of solid food, and rather over three pints of liquid food.

QUESTIONS FOR CHAPTER III.

1. Of what does *meat* consist?
2. What kinds of animal food are most nutritious?
3. What is the effect of *cooking* upon meat?
4. What is the composition of *eggs?*
5. What effect is produced upon eggs by boiling?
6. What is the composition of *milk?*
7. How is the butter extracted from milk?
8. Why should it be carefully purified?
9. What is cheese, and how is it made?
10. What are the ingredients of wheat flour?
11. Describe the making of bread.
12. What is the use of fermenting bread with yeast?
13. What is the process of making *wine?*
14. What is *beer*, and how is it made?
15. What are the *vegetables* principally used for food?
16. What is the effect of cooking upon vegetables?
17. What are necessary qualities of wholesome food?
18. How much meat is required per day by a healthy man? how much bread? how much fat? how much liquid?

CHAPTER IV.

DIGESTION.

Necessity for Food.—Nature of Digestion.—Alimentary Canal—its different Parts.—Digestive Fluids.—Mastication.—The Teeth.—Incisors.—Canines.—Molars.—Their different Functions.—Saliva.—Salivary Glands.—Composition of Saliva—its double Function.—Action of the Tongue.—Œsophagus—its Peristaltic Action.—Deglutition.—The Stomach—its lining Membrane.—Gastric Tubules.—Gastric Juice—its Secretion.—Peristaltic Movements of the Stomach.—Composition of the Gastric Juice.—Pepsine.—Lactic Acid.—Action of Gastric Juice on the Food.—It is a Ferment.—Digestibility of Food.—Food should be properly cooked—should be taken in moderate quantity—with regularity.—The small Intestine.—Follicles of Lieberkühn.—Intestinal Juice—its action on Starch.—Pancreatic Juice—its Composition—its action on Fat.—The Chyle.—Peristaltic Movement of Intestine.—Changes of Food in the Alimentary Canal.—End of Digestion.

29. **The demand for Food.**—Why is it that we require food?

It is because the human body is not an inert and senseless machine, but a collection of living organs, incessantly active, and constantly employed in performing their allotted functions. Corresponding with this activity a continuous change goes on in the substance of the organs, by which their materials are constantly decomposed and constantly renewed. Throughout the interior of the frame nature is incessantly engaged in taking apart the tissues of which the body is composed, and in making them over again of new and fresh ma-

terials. We shall hereafter see in what manner this process of the unraveling and recomposition of the animal frame is accomplished, and what peculiar substances are produced in consequence. For the present it is sufficient to know that it is continually going on, and that the healthy tissues of the body are accordingly always renewed and always ready to perform their work.

This requires a constant supply of new material from without.

But, beside this, in young children a provision is also necessary for their growth and development. The newly-born infant weighs from six to seven pounds; at the end of a year his weight has increased to twenty pounds; and at twenty-five years of age it has reached one hundred and forty pounds. During all this time new material has been added to the body, not only sufficient to compensate for its waste of tissue, but also in surplus quantity to provide for its increasing size. This new material has been taken with the food, has been distributed over the body, and disseminated every where throughout the substance of the tissues.

30. **Nature of the Digestive Process.**—But the food itself will not serve directly for the nourishment of the animal frame. First of all, because the ingredients of our food are for the most part solid, and they must be liquefied before they can be absorbed by the membranes and circulate with the blood; and, secondly, because the ingredients of the food, the animal and vegetable juices, the starch, fat, albumen, etc., are not the same with the ingredients of the human body. They are nutritious, but only because they are capable of being converted into other substances, which are

then appropriated by the internal organs. All the substances used as food, therefore, are subjected to a kind of preliminary disintegration and metamorphosis. Meat, bread, fruits, vegetables, must all be first reduced to a new condition before they can finally take part in the nutrition of the body. Their ingredients are compelled to undergo a transformation, which fits them at last to be absorbed by the living tissues.

This liquefaction and transformation of the ingredients of the food is the process of *Digestion.*

31. **General Structure and Arrangement of the Digestive Apparatus.**—The digestion of the food is performed in a long tube or canal, called the "Alimentary Canal," which commences at the mouth, and runs continuously from one end of the body to the other. If we examine its different parts, we shall see, first, that they differ from each other in size, form, and structure, and are accordingly known by different names, such as the "pharynx," the "œsophagus," the "stomach," and the "intestine;" and, secondly, that there are different animal fluids, called the "digestive secretions," which are poured into the alimentary canal at different points, and there come into contact with the ingredients of the food. It is these secretions which have the power of acting upon the food, so as to dissolve it and transform its materials in the manner described above.

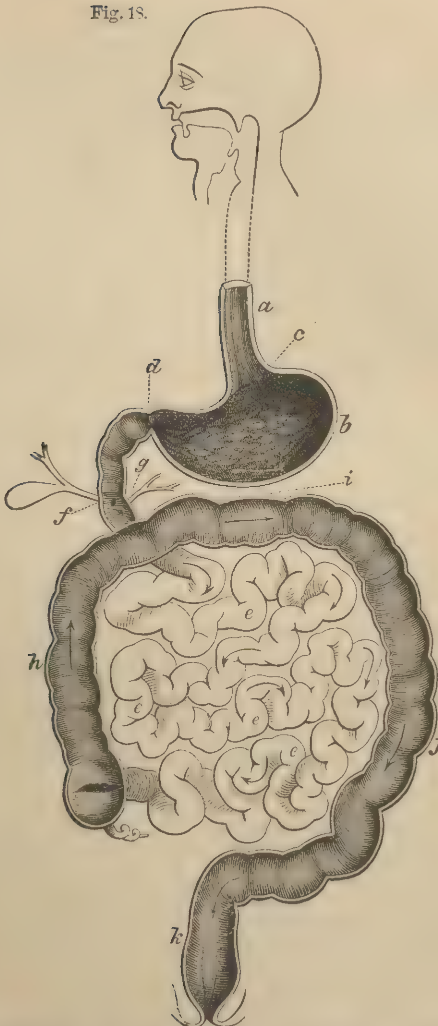
Now the mode in which this action is performed is very remarkable. Each one of the digestive secretions contains a peculiar albuminous matter, different from those of all the rest, and having the power of acting like a ferment. When this ferment comes into contact with certain ingredients of the food, it at once produces a change in their condition, so that they are

transformed, and become capable of being used for the nourishment of the body. Thus the different ingredients of the food are acted upon, in the different parts of the alimentary canal, by different digestive fluids; and as the food gradually passes from above downward, its various elements are successively transformed, and the digestion of the whole is finally accomplished.

At the commencement of the alimentary canal (Fig. 18) we find, as already mentioned, the cavity of the *Mouth*. This cavity is guarded in front by the opening of the lips, and behind by the muscular walls of the throat, or *Pharynx*, which can close at will, so as to prevent the passage of substances from the mouth backward. Beyond the pharynx comes a long and narrow tube, the gullet or *Œsophagus* (*a*), which runs nearly straight downward along the back part of the neck and chest until it reaches the abdomen. Here it terminates in the *Stomach* (*b*), which is a large, flask-shaped expansion, lying across the cavity of the abdomen, just beneath the lower extremity of the breast-bone. Like the mouth, the stomach is guarded at each end by muscular bands, which sometimes shut up its orifices, and sometimes open to allow the passage of the food. The first of these orifices, situated on the left side, and communicating with the œsophagus (*c*), is called the "cardia;" the second, situated on the right side (*d*), is called the "pylorus."

Beyond the pylorus the alimentary canal becomes a long and very narrow tube, not more than an inch and a half in width, but nearly twenty-five feet in length, called the *Small intestine* (*e*). The small intestine is folded upon itself with many different turns, so that it forms a convoluted mass, occupying a large part of the

Fig. 18.



Human Alimentary Canal.—*a.* Œsophagus ; *b.* Stomach ; *c.* Cardiac orifice ; *d.* Pylorus ; *e.* Small intestine ; *f.* Biliary duct ; *g.* Pancreatic duct ; *h.* Ascending colon ; *i.* Transverse colon ; *j.* Descending colon ; *k.* Rectum.

space within the abdomen. At its upper portion, a few inches below the pylorus, two slender tubes open into its cavity, coming one from the liver, the other from the pancreas, called the *Biliary* and *Pancreatic ducts* (*f*, *g*). They serve to convey into the intestine at this point two important secretions, viz., the bile and the pancreatic juice. The small intestine itself is provided with a lining membrane, which varies somewhat in structure in different parts of the tube. It terminates in the lower part of the abdomen, near the right side, where it opens by a narrow orifice into the last division of the alimentary canal, viz., the *Large intestine* (*h*, *i*, *j*, *k*).

The large intestine, so called because it is wider than the rest, is the receptacle for the refuse parts of the food which have not been digested. It passes upward along the right side of the abdomen, where it is called the "ascending colon" (*h*); then to the left side, as the "transverse colon" (*i*); then descends along the left side of the abdomen as the "descending colon" (*j*); and finally passes into the pelvis, where it terminates under the name of the "rectum" (*k*).

In order to understand the process of digestion, we must examine the changes which the food undergoes in each successive division of the alimentary canal.

The first of these divisions is the mouth. When first introduced into this cavity, the food is subjected to two processes, which are very simple, but very important. It is *masticated*, and at the same time mingled with the *saliva*.

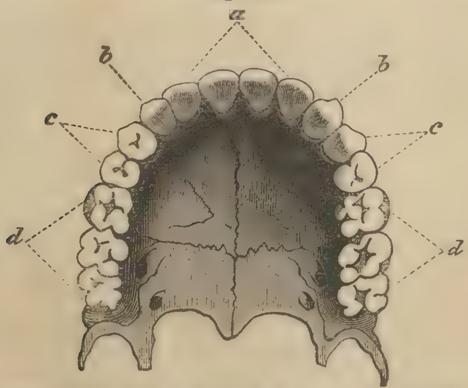
32. **Mastication.**—The mastication of the food consists in its grinding up or comminution by the action of the teeth. The digestive fluids, which are to dis-

solve the food in the stomach and intestine, could not readily act upon it if it were swallowed in a crude and solid mass. It must first be triturated and reduced to a state of fine subdivision, in order to prepare it for the digestive process; in the same way as a piece of loaf-sugar if simply placed in water dissolves slowly and with difficulty, but if first crushed into fine grains is rapidly attacked and liquefied by the solvent fluid.

The organs of mastication are the *Teeth.* They are composed of a strong bony substance, and are firmly fixed in their places by strong "roots," which penetrate into the substance of the jaws. The projecting part of each, which is called the "crown" of the tooth, is covered with a layer of exceedingly dense material, the "enamel," which, as we have already seen, is the hardest substance in the body, and capable of resisting the strongest pressure.

The teeth are thirty-two in number, viz., sixteen in each jaw (Fig. 19). They vary somewhat in size and

Fig. 19.



Human Teeth—Upper Jaw.—*a.* Incisors; *b.* Canines; *c.* Anterior molars; *d.* Posterior molars.

shape, and are adapted, in different parts of the jaw, to somewhat different uses. The four teeth in the front part of each jaw are the *Incisors*, or "cutting teeth." They are rather flat, with a thin, chisel-like edge running from side to side. As their name indicates, these teeth are adapted to cutting the food, so far as this is required; as in biting off the stems of juicy plants and certain kinds of vegetables and fruits. They correspond to the gnawing teeth of mice, squirrels, rabbits, and other similar species, in which they are very highly developed, and capable of cutting through the hardest substances.

Immediately outside the incisors are the *Canine* teeth (*b*), one on each side of each jaw. They are somewhat pointed in form, and correspond to the large and prominent "tusks" of the carnivorous animals, which are so formidable as weapons of offense for wounding and seizing their prey. In the human species they do not differ very much in their function from the incisors.

Behind the canine teeth, and occupying all the rest of the jaw, are the *Molars* (*c*, *d*), five in number on each side, viz., two anterior and three posterior. They are very thick and strong, and have rather flat surfaces covered with conical elevations. Most of them are provided with two or more spreading roots, which fix them more firmly in the jaws, and enable them to resist the pressure from side to side. These are the most powerful and important teeth for the comminution of the food. The incisors and canines have less force, because they are situated in the front part of the jaws, and are adapted only for cutting or piercing substances which offer but little resistance. But when the food is once taken into the mouth we carry it backward, be-

tween the strong molar teeth, which are situated just within the muscles upon the sides of the jaws. Then, by repeated lateral movements of the jaws from right to left, the food is ground and comminuted between their hard surfaces, as it would be between two mill-stones, until its different parts are reduced to a fine homogeneous mixture.

We can readily appreciate the greater power of the molar teeth by attempting to use them upon different substances. We can easily bite off a slender thread or a juicy vegetable by placing it between the incisors. But when the substance is more resisting, like a hard crust or a woody stem, we instinctively place it between the molars in the back part of the mouth, when it is seized and crushed with all the power of the strong muscles situated on the sides of the jaws.

In the movements of mastication it is the lower jaw only which moves. The upper remains stationary, as we can easily convince ourselves by placing the fingers upon the sides of the face while mastication is going on. We can also feel in the same way the strong muscles in this situation, which swell and become rigid whenever the lower jaw is pressed firmly against the upper.

33. **Saliva.**—But the mastication of the food is very much assisted, and at the same time rendered more efficacious, by the *Saliva* which is mingled with it in the cavity of the mouth.

The saliva is produced by various glandular organs situated in and near the mouth. These organs are of four different kinds. First, the *Parotid* gland, situated beneath the skin immediately in front of the ear; second, the *Submaxillary* gland, just within the angle of the lower jaw; third, the *Sublingual* gland, beneath the

side of the tongue; and, fourth, the *Mucous glandules*, situated in the lining membrane of the mouth, particularly on the inside of the lips and cheeks. These various glandular organs produce four different kinds of fluid, which vary in consistency, some of them being more watery, others more viscid; but they are all finally mingled together to form the saliva.

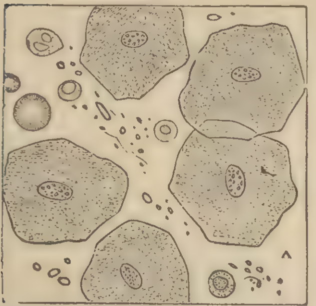
The saliva is constantly secreted in moderate quantity, sufficiently to lubricate the lining membrane of the mouth, and to keep it moist and pliable. Its flow is excited, however, in greater abundance by any thing which stimulates the sense of taste, such as sweet, sour, or bitter substances. This effect is produced through the action of the nervous system. Even the sight or sometimes the thought of attractive articles of food, when the appetite is excited, will stimulate the discharge of saliva, and, as it is commonly expressed, "bring the water to the mouth." The movement of the jaws, as in speaking, and more especially in mastication, will also increase the quantity of saliva; and the action of swallowing has, for the moment, a similar effect.

But the flow of saliva is stimulated, most of all, by the ordinary mastication of the food in eating; when the excitement of the taste, the movement of the jaws, and the action of swallowing all combine to excite the activity of the glandular organs. It is then poured out in the greatest abundance, to perform its office in the preparation of the food.

The saliva is a thin, colorless, slightly viscid, and alkaline fluid. When first discharged it is somewhat frothy and opaline in appearance, but after it has remained at rest for a short time its upper portion be-

comes nearly clear, while a fine white flocculent substance is deposited at the bottom. This deposit, when examined by the microscope (Fig. 20), is seen to be composed of minute granules, a few oil globules, and a quantity of thin, flat, scale-like bodies, or cells, called "epithelium cells," which have been separated from the surface of the lining membrane of the mouth. There are also a few smaller rounded cells mingled with the rest, which are derived from the mucous glandules of the mouth.

Fig. 20.



Deposit from the saliva, showing epithelium cells, etc.; highly magnified.

The saliva has the following composition in 1000 parts:

Composition of Saliva in 1000 parts.

Water	995.16
Albuminous matter	1.34
Mineral ingredients	1.88
Mixture of epithelium	1.62
	1000.00

It is accordingly a very thin fluid, containing but a small quantity of solid substances in proportion to its watery parts.

The albuminous matter of the saliva is called *Ptyaline.* It is owing to the presence of this albuminous matter that the saliva is somewhat viscid, and that it readily becomes frothy when mixed with air.

The *entire quantity* of the saliva produced in twenty-four hours has been calculated by ascertaining how

much is naturally absorbed by the food during mastication, and adding this quantity to that gradually secreted in the intervals between the meals. It is thus found that in an adult man very nearly three pounds of saliva are secreted every day. This quantity, however, is not all discharged from the mouth. By far the larger portion is secreted during mastication, and mingled with the food which is taken into the stomach.

34. **Function of the Saliva.**—The function of the saliva is twofold.

First of all, it *assists mastication.* This can easily be seen by noticing the difficulty of masticating perfectly dry substances. Pounded crackers, for example, or dry meal, are masticated with extreme difficulty until they have become moistened with a certain quantity of saliva. After this the process is much easier. The act of swallowing is also assisted to an important degree by the presence of the saliva. It is almost impossible to swallow a perfectly dry mouthful until it has been moistened and lubricated by the saliva. The same thing happens in animals when the saliva can no longer find its way into the cavity of the mouth. In the horse, for example, it has been found that when the saliva of the parotid glands alone has been prevented from passing into the mouth, the animal is nearly four times as long in masticating and swallowing a given quantity of grain as when the natural flow of the secretion is undisturbed.

The saliva is also useful by *assisting in digestion.* It does this simply by moistening the food and preparing it for the action of the other digestive fluids, particularly those of the stomach. For the juices of the stomach, which, as we shall hereafter see, are very important

in digestion, require to penetrate readily all parts of the alimentary mass in order to produce their proper effect. This they can do much more readily if the food be already moistened than if it be dry and resisting. This is true of almost any fluid that requires to be absorbed by a solid substance. If a perfectly dry sponge be thrown upon the water, it will float upon the surface for a long time almost untouched. But if it be first made damp or slightly moistened throughout, it then rapidly absorbs the water as soon as it touches the surface, and sinks at once to the bottom.

It will be easily understood, therefore, how important it is that the process of mastication be regularly and thoroughly accomplished. It must never be neglected, nor performed in a hurried and imperfect manner; for if so, the subsequent digestion of the food will certainly be delayed and obstructed, and perhaps prevented altogether. And if the food which is taken into the stomach be not digested as it should be within the natural period, it then becomes a source of irritation, and is liable to produce a variety of injurious effects before it is finally discharged from the alimentary canal.

35. **Action of the Tongue in Mastication.**—In the mastication of the food an important office is also performed by the *Tongue.*

First, because this organ is the principal seat of the sense of taste; and it is by this sense that we judge of the fitness of certain substances to be used as food. Those substances which are sound, nutritious, and well cooked are usually agreeable to the taste and are admitted without delay; while such as are decayed, of inferior quality, or improperly prepared, are at once detected by a more or less disagreeable flavor. This dis-

agreeable flavor notifies us of the presence of some substance in the food which is unfit for digestion, and accordingly it may be rejected before it has been conveyed to the cavity of the stomach.

Secondly, the tongue possesses, in a very exquisite degree, the sensibility of touch. By this means it can appreciate all the physical qualities of the food introduced into the mouth, and can ascertain at once whether it has been sufficiently masticated, or whether there yet remain any portions which are still crude and resisting. Endowed also by its muscular apparatus with a power of varied and flexible motion, it carries the food about from one part of the mouth to another, so that the whole is finally subjected to the action of the teeth.

36. **Combined Effect of the Saliva and Mastication.**— The preparation, accordingly, which the food undergoes in the mouth is the combined effect of its mastication and its mixture with the saliva. None of its ingredients are as yet changed or decomposed, but they are all present in the masticated mass, though no longer distinguishable by the eye. The food is simply triturated and disintegrated by the teeth; and at the same time, by the movements of the jaws, cheeks, and tongue, it is intimately mingled with the saliva, which is worked into its substance until the whole is reduced to a soft, pasty material, of uniform consistency, and ready to be penetrated by the digestive fluids.

This softened material is then brought together by the movements of the tongue, which penetrates into every part of the mouth, searching busily in all its corners and cavities until it has collected the masticated food into a single mass upon its upper surface. The

mass is then pressed backward by the muscular force of the organ, and carried through the opening of the pharynx into the upper part of the œsophagus.

Here it passes beyond the control of the will. All the movements of the mouth, the jaws, and the tongue which we have heretofore described are voluntary in their character, and may be set in motion or arrested, hastened or retarded, at will. But from the moment the food passes the pharynx and enters the œsophagus it is no longer under our control, and is received by another set of organs, whose action is entirely involuntary.

37. **Deglutition.**—The œsophagus, as we have already mentioned, is a narrow tube, extending from the pharynx downward to the stomach. It is provided throughout its length with a double layer of muscular fibres, some of which are placed longitudinally in its walls, while others run round it in a circular direction, thus clasping the tube like the fingers of a closed hand.

When the food enters the upper part of the œsophagus, these circular fibres contract upon it from above and force it onward; while the longitudinal fibres at the same time draw the lower part of the tube upward, and open a passage for the food in a downward direction. The same action is repeated successively in every part of the œsophagus, so that a continuous undulating or wave-like contraction moves steadily from above downward through the whole length of the œsophagus, carrying the food before it in a rapid but gentle and uniform manner.

This movement of the œsophagus is called the "peristaltic," or *vermicular* action, because it resembles the motion of a worm in crawling over the ground. It at last reaches the cardia at the lower end of the tube;

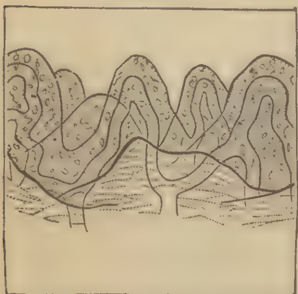
when this orifice yields to the pressure from above, and the food, passing through it, is finally conveyed into the cavity of the stomach. The whole process by which the food is thus carried from the mouth to the stomach is called the act of swallowing, or "*Deglutition.*"

38. **The Stomach and its Lining Membrane.**—The stomach, as we have already seen, is an enlargement of the alimentary canal, forming a rounded cavity or sac. It is here that the most important part of the digestive process is performed; so that the food, which has already been triturated and softened by mastication, now begins to be actually liquefied and dissolved, and at the same time transformed and altered in its properties.

The stomach consists of two principal parts, viz., first, a *lining membrane*, and, secondly, a *muscular coat.*

Its lining membrane is thick, soft, and abundantly supplied with blood-vessels. Its inner surface is not perfectly smooth, but is raised into little ridges and projecting eminences (Fig. 21). In the middle portions of the stomach, and toward the pylorus, these elevations are rather pointed in form, and generally flattened from side to side. Each one contains a small blood-vessel, which turns upon itself in a loop at the extremity of the projection, and communicates freely with the surrounding vessels.

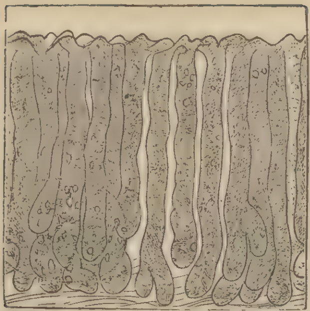
Fig. 21.



Inner surface of the lining membrane of the pig's stomach, as seen in vertical section, magnified 420 times; showing its conical elevations, and the blood-vessels contained in them.

The substance of the lining membrane forms an act-

Fig. 22.



Lining membrane of the pig's stomach, showing its whole thickness, with the gastric tubules; magnified 70 times.

ive and peculiar glandular apparatus. Its whole thickness is filled with little cylindrical or tubular organs, called the "gastric tubules" (Fig. 22). These little tubes terminate by rounded ends beneath, and open upon the upper surface of the membrane by minute orifices, situated between the pointed elevations already described. The small blood-vessels penetrate every where between the tubules, and form an abundant net-work about their sides.

39. **The Gastric Juice.**—The stomach exerts its action upon the food by means of a liquid secretion, which is produced by its lining membrane. This fluid is the *Gastric Juice.*

The gastric juice is poured out from the lining membrane of the stomach at the moment when the food enters its cavity. The lining membrane is sensitive to the contact of the food, and is excited to pour out its secretion, just as the glands in the neighborhood of the mouth pour out their saliva when the food is undergoing mastication. But the action of the stomach takes place without our consciousness. The excitement of its lining membrane is not communicated to us by any sensation, and takes place as one of the involuntary actions of the interior of the body.

During the intervals of digestion, therefore, the stomach is quiescent and empty. But no sooner does the food pass the cardiac orifice and enter its cavity than

an influx of blood takes place into its vessels, its lining membrane becomes swollen and congested, and of a bright red color, and its tubules begin to secrete a clear, watery, acid fluid. This fluid exudes from the lining membrane in a multitude of minute drops like the perspiration from the surface of the skin, and, coming in contact with the food, begins at once to act upon its ingredients.

40. **Peristaltic Action of the Stomach.** — At the same time another action is excited in the stomach of a different nature. This is the action of its muscular coat.

The muscular fibres of the stomach, like those of the œsophagus, are partly longitudinal and partly circular. When the food is introduced, and the flow of the gastric juice begins, they are also stimulated to contraction, and commence a series of movements from side to side, and from one end of the organ to the other. These are the *peristaltic movements* of the stomach. They produce a kind of gentle kneading or continuous churning of the food, by which it is moved slowly about in the interior of the organ. They are like the movements of mastication performed in the mouth, except that they are involuntary, like the peristaltic action of the œsophagus, and are performed without knowledge. Their effect is to work the gastric juice, as fast as it is secreted, into the interior of the masticated food, until it penetrates the mass equally throughout.

These movements have occasionally been seen, both in men and animals, in cases where an opening has been made into the stomach either accidentally or by a surgical operation. At the same time, the gastric juice has been obtained and subjected to examination.

41. **Ingredients of the Gastric Juice.**—When the gas-

tric juice is thus collected from the cavity of the stomach, it is found to be clear, transparent, of a light amber color, and very distinctly acid. It contains the following ingredients:

Composition of the Gastric Juice in 1000 parts.

Water	975.00
Albuminous matter	15.00
Lactic acid	4.78
Mineral ingredients	5.22
	1000.00

The albuminous matter of the gastric juice is termed *Pepsine*, owing to its active properties in the digestion of the food. It may be coagulated by boiling, and also by the addition of a large quantity of alcohol. When separated by either of these means and dried, it appears as a fine white powder, which may be again dissolved in water. This is the most important ingredient of the gastric juice.

The *Lactic acid* is the same substance which is produced from sugar in the souring of milk. It is in a very dilute form in the gastric juice, but is necessary to its digestive properties; for the pepsine will not act upon the food unless it be dissolved in an acid fluid.

The *Mineral ingredients* of the secretion are also present in small quantity. They consist of common salt, together with combinations of potash, lime, magnesia, and iron.

42. **Action of Gastric Juice upon the Food.**—The gastric juice, constituted as above, has a very remarkable effect upon the food. For if a small portion of meat, bread, boiled white of egg, or cheese, be cut into thin slices, placed in gastric juice, and kept at a warm temperature, the alimentary substance soon begins to be

disintegrated and liquefied by the action of the fluid. This effect first shows itself upon the outer surface of the substances acted on, which become more transparent and softer, and thus gradually melt away. If the mixture be gently agitated, so as to shake off the softened parts, the process goes on more rapidly. The gastric juice penetrates deeper and deeper into the interior, softening and dissolving as it goes, until the whole mass is finally reduced to the form of a fluid mixture.

But if the fluid mixture thus produced be examined more closely, it will be found that all the ingredients of the food have not been equally affected. In fact, it is only the *albuminous* constituents which are dissolved by the gastric juice, while the starchy and oleaginous matters are not altered. But as the food, when taken, consists of starchy and oleaginous substances united and enveloped by albuminous matters, the solution of the latter sets free the other ingredients from their combination.

Thus bread consists of starch entangled with the solidified glutinous matter of the flour. When the glutinous matter is dissolved by the action of the gastric juice, the starch is consequently disintegrated at the same time, though it still retains its other peculiar properties.

Again, cheese consists of the solidified caseine of the milk, with the oily or buttery milk globules imbedded in its substance. The caseine is dissolved and liquefied by the gastric juice, but the oily parts remain unchanged, and simply rise to the top and float upon the surface of the watery fluid.

The gastric juice accordingly appears to act upon the whole mass of the food, but in reality it is only by

dissolving that large portion of its ingredients which consist of albuminous matter.

Now the action of the gastric juice in this process is a very peculiar one, and depends upon the properties of the pepsine which it contains. This substance acts as a *ferment*, and, simply by coming in contact with the albuminous matter, changes its nature and reduces it to the liquid form. For albumen, after being digested by the gastric juice, is no longer albumen, but has been transformed and converted into something else. This new substance is termed *Albuminose*, and is distinguished by peculiar properties. Thus white of egg, in its natural condition, is coagulated by boiling, and is usually taken as food in this solid and coagulated form; but after it has been liquefied in the manner above described, and converted into albuminose, it can not again be coagulated by heat, but remains fluid, and is ready to be absorbed by the blood-vessels.

Like the other ferments which have been already described, the pepsine of the gastric juice, in order to produce its effect, must have a moderately warm temperature, neither too hot nor too cold. The gastric juice will not act upon the food when near the freezing point of water, neither will it have any effect if raised to the neighborhood of a boiling temperature. It must be intermediate between the two; and its greatest activity is about 100 degrees Fahrenheit, which is exactly the temperature of the interior of the living stomach.

In some instances the action of the gastric juice is very curious. Thus milk, if taken in a fluid form, is first coagulated by the fluids of the stomach. It is owing to this property that *rennet*, which is nothing else than the dried fluids of the calf's stomach, causes the

coagulation of milk in the manufacture of cheese. In digestion this effect is instantaneous, or nearly so. But soon afterward the pepsine begins to act upon the coagulated caseine, and finally reduces it again to the liquid form. Thus the same substance, during digestion, is first solidified, and afterward dissolved by the gastric juice. This proves that the act of digestion does not consist in a simple solution, but is an actual transformation of the albuminous substances.

The gastric juice is the most abundant of all the digestive fluids. It continues to be produced by the lining membrane so long as any food remains undigested in the stomach. The quantity which is first secreted acts upon a corresponding portion of the albuminous matters. The liquefaction of these albuminous matters causes, as we have already seen, a disintegration of the food previously combined and agglutinated by their substance, and these disintegrated portions pass at once through the pylorus into the cavity of the small intestine. A fresh quantity of gastric juice is at the same time secreted, does its work in a similar manner, and is carried with another portion of the debris of the food into the intestine. This process goes on until the whole of the food, thus successively broken down and disintegrated by the solution of its albuminous portions, has been removed from the cavity of the stomach, and carried downward into the channel of the small intestine.

When this is accomplished, the secretion of gastric juice by the stomach comes to an end, the congestion of its lining membrane disappears, its peristaltic action ceases, and the entire organ returns to its ordinary quiescent condition.

The stomach, accordingly, is alternately in two differ ent conditions, corresponding to the digestive process, viz., a condition of rest and a condition of activity. While digestion is going on, it is in active secretion; during the intervals of digestion it remains quiescent.

43. **Digestibility of Food.**—The digestibility of different kinds of food varies considerably. Some of them are disposed of in a comparatively short time; others take a longer period. This difference is, to a certain extent, a matter of common experience, since every one is conscious that certain articles of food require a longer time for digestion than others. Dr. William Beaumont had an opportunity, many years ago, of examining this point in a patient who had a permanent opening in the stomach, the result of a gun-shot wound. He compared the time required for the digestion of many different kinds of food, some of which are enumerated in the following list:

TIME REQUIRED FOR DIGESTION ACCORDING TO DR. BEAUMONT.

	Hrs.	Min.		Hrs.	Min.
Pig's feet	1	00	Roasted beef	3	00
Tripe	1	00	" mutton	3	15
Trout (broiled)	1	30	Veal (broiled)	4	00
Venison steak	1	35	Salt beef (boiled)	4	15
Boiled milk	2	00	Roasted pork	5	15
Roasted turkey	2	30			

These results would not always be precisely the same for different persons, since there are variations in this respect according to age and temperament. Thus, in most instances, mutton would probably be equally digestible with beef, or perhaps more so; and milk, which in some persons is easily digested, in others is disposed of with considerable difficulty. But, as a general rule,

the comparative digestibility of different substances is no doubt correctly expressed by the above list.

44. **Conditions requisite for healthy Digestion.**—The healthy action of the digestive process must be provided for by careful attention to various particulars.

First of all, the food should be of good quality and *properly cooked.* The best methods of preparation by cooking are the simplest, such as roasting, broiling, or boiling. Articles of food which are fried are very apt to be indigestible and hurtful, because the fat used in this method of cooking is infiltrated by the heat, and made to penetrate through the whole mass of the food. Now we have seen that fatty substances are not digested in the stomach, as the gastric juice has no action upon them. In their natural condition they are simply mixed loosely with the albuminous matters, as butter when taken with bread or vegetables, or the adipose tissue which is mingled with the muscular flesh of meat; and the solution of the albuminous matters in the stomach, therefore, easily sets them free, to pass into the small intestine. But when imbibed and thoroughly infiltrated through the alimentary substances, they present an obstacle to the access of the watery gastric juice, and not only remain undigested themselves, but also interfere with the digestion of the albuminous matters. It is for this reason that all kinds of food in which butter or other oleaginous matters are used as an ingredient, so as to be absorbed into their substance in cooking, are more indigestible than if prepared in a simple manner.

It is also important, more particularly in all kinds of vegetable food, that the cooking should be thorough and complete. This is necessary in order that their

texture may be sufficiently softened and their starchy ingredients properly prepared. For raw starch is exceedingly difficult of digestion, while that which has been boiled, or heated in any way in contact with water, absorbs moisture, as we have seen, so that its grains become softened, and are then easily acted on by the digestive fluid.

Secondly, the food should be taken in *moderate quantity* at a time. If an excessive amount be swallowed at once, it appears to exert a paralyzing influence upon the stomach, which is overpowered by the unaccustomed load, and fails to act with energy upon the alimentary materials. This danger is especially to be avoided when the appetite is voracious, after an unusually long abstinence. The excessive desire for food at such times is an unnatural one, and should not be immediately gratified to its fullest extent, since it is liable to overtax the capacity of the stomach, and thus produce a disturbance in the digestive function.

Thirdly, the food should be *taken with regularity*, and about the same time each day. The digestive organs are subjected to the influence of habit in this respect, for some reason which we do not fully understand. They accomplish their work more promptly and thoroughly when the food is taken at the accustomed time and in the accustomed manner than if it be taken irregularly and out of season. This fact was noticed so long ago as the time of Hippocrates, who says in his Treatise on Regimen that if a man who has not been accustomed to take food in the middle of the day should do so, he is liable to be oppressed and disturbed by it; while those who are in the habit of dining at this time, if they omit the usual meal, are equally affected,

and perhaps lose their appetite for the rest of the day. In some persons the system is exceedingly sensitive to any such irregularity, and in all the process of digestion is more or less liable to be affected by it.

Lastly, the secretion of the gastric juice and the digestion of the food are much influenced by the *condition of the nervous system.* It has been found, by the experiments of Dr. Beaumont and others, that irritation of the temper and other moral causes will frequently diminish or altogether suspend the natural flow of the gastric fluids. Any feverish action in the system or any excessive fatigue is liable to produce the same effect. Every one is aware how readily any mental disturbance, such as anxiety, anger, or vexation, will take away the appetite and interfere with digestion. Any injurious nervous impression, occurring especially at the *commencement* of digestion, seems to produce an effect which lasts for a considerable period; for it is often noticed that when any annoyance, hurry, or anxiety occurs soon after the food has been taken, though it may last but for a few moments, the digestive process is not only endangered for the time, but is liable to be permanently disturbed during the entire day.

In order, therefore, that digestion may go on properly in the stomach, food should be taken only when the appetite demands it, and as nearly as possible at regular intervals; it should be properly prepared by cooking, and thoroughly masticated at the outset; and, finally, both mind and body, particularly during the commencement of the process, should be free from any unusual or disagreeable excitement.

45. **Entrance of Food into the small Intestine.** — As the disintegrated and partly liquefied food passes out

through the pylorus into the small intestine, it consists, first, of the gastric juice, together with the albuminous matters which it holds in solution; second, of the starchy substances which have been set free from the other ingredients of the food, but not otherwise altered; and, third, of the oleaginous matters which are also unchanged by the gastric juice. The last two substances, however, are now digested by the action of the fluids which are poured into the cavity of the small intestine.

46. **The Intestinal Juice and Digestion of Starch.**—The first of these fluids is the *Intestinal Juice.* The intestinal juice is secreted by a vast number of small tubular glands called the "Follicles of Lieberkühn," which are thickly set throughout the whole extent of the lining membrane of the intestine (Fig. 23). Like the tubules of the stomach, these bodies are cylindrical in form, with rounded ends below, and opening by little mouths upon the inner surface of the intestine. Owing to the great length of this part of the alimentary canal, and consequently the extent of its lining membrane, these follicles are exceedingly numerous. The intestinal juice which they secrete is colorless, slightly alkaline, and of a viscid consistency. It contains an albuminous ingredient, somewhat similar to that produced by the mucous glandules of the mouth.

Fig. 23.

Follicles of Lieberkühn, from the small intestine.

Now the intestinal juice, thus secreted, has the power of acting upon starch with great rapidity at the

temperature of the living body, and of converting it into sugar. If a little of the fresh intestinal juice be mingled with boiled starch and kept in warm water for a few seconds, the starch begins to disappear from the mixture, and sugar to take its place; and in a short time the whole of the starch will have undergone the same transformation.

This change is accomplished by the action of the albuminous ingredient of the intestinal juice. Like the pepsine of the gastric juice, it acts as a ferment; and by simply coming in contact with the starchy matters of the food at a warm temperature, it causes them to change their properties, and transforms them into sugar. When the starchy substances have thus been converted into sugar, their digestion is accomplished; for they have then become liquefied, and accordingly may be readily dissolved by the fluids of the intestine.

When the food passes into the small intestine, therefore, it meets with the intestinal juice, which is secreted with activity at that time; and by the contact of this fluid, its starch is rapidly transformed into sugar, and then held in solution by the intestinal fluids.

47. **Pancreatic Juice.**—There is still another secretion which is mingled with the food in the cavity of the intestine, viz., the *Pancreatic Juice.* As its name indicates, this fluid is the production of the "pancreas," a gland situated near and a little behind the lower border of the stomach. The pancreas discharges its secretion into the upper part of the small intestine, a few inches below the situation of the pylorus (Fig. 18, *g*).

The pancreatic juice, as it enters the intestine, is a clear, colorless, alkaline and rather viscid fluid, somewhat similar in appearance to the intestinal juice. It contains the following ingredients:

Composition of the Pancreatic Juice in 1000 parts.

Water	900.76
Albuminous matter	90.38
Mineral ingredients	8.86
	1000.00

It contains, therefore, a much larger proportion of albuminous matter than either saliva or the gastric juice; and, accordingly, it is more viscid than either of these secretions, sometimes almost resembling white of egg in consistency.

This albuminous matter is termed "Pancreatine." It may be coagulated by boiling, by the addition of an excess of alcohol, and by various other chemical means. It is the principal and most active ingredient of the pancreatic juice.

48. **Action of the Pancreatic Juice on Fat.** — The most important property of this secretion is its action upon the oleaginous matters. These substances, as we have seen, are not digested in the stomach. They are only melted by the warmth of the body, or by the solution of the albuminous matters are set free from the tissues in which they were entangled. In the stomach, therefore, they are always easily recognized, floating in the form of oily drops and globules among the other ingredients of the food.

But in the intestine these oily drops are no longer to be seen. In place of them there appears a white milky-looking fluid, mingled with the other substances in this part of the alimentary canal, which smears over its internal surface, and collects in the little folds and hollows of its lining membrane. This white fluid is the *Chyle.* It contains all the oleaginous matters of the food, but so changed in their condition that they are no

longer distinguishable by the naked eye. If we examine it by the microscope, we see that it is filled with excessively minute granules of fat, so fine that they can hardly be measured, and suspended in the albuminous liquids like an emulsion.

The chyle is, in fact, an emulsion, which has been produced by the action of the pancreatic juice upon the oily particles of the food.

If we take a quantity of fresh pancreatic juice, and shake up with it a little olive oil or other fatty substance, the same effect is immediately produced. The oil is at once disintegrated and broken into minute particles, which are then disseminated through the mixture, forming a perfectly white, opaque, milky-looking fluid. This action is accomplished by the albuminous ingredient of the pancreatic juice, which is known as "pancreatine." We have already seen, in a former chapter (p. 60), that fresh white of egg will produce this effect upon oil when shaken up with it in a glass vessel. Now pancreatine is very similar in its properties to the white of egg, and especially resembles it in this action which it exerts upon the oily parts of the food, by which they are converted into an emulsion.

This change, when accomplished, is sufficient to complete the digestion of the fat; for in the emulsioned form it is capable of being absorbed by the vessels, and thus received into the general current of the circulation.

49. **Peristaltic Movement of the Intestine.**—At the same time that the changes which have now been described take place, the elements of the food, mingled with the various digestive fluids, are carried from above downward by the peristaltic action of the intestine. For the intestine, like the œsophagus and the stomach,

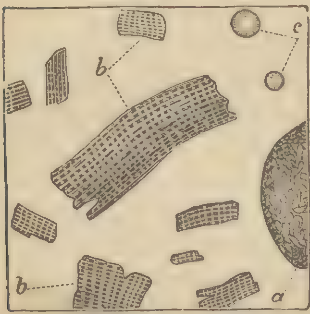
is provided with a double muscular coat, consisting of longitudinal and circular fibres. The action of these fibres may be seen very plainly in the intestines of the ox or sheep, immediately after they are removed from the body of the slaughtered animal. Indeed, it is in this part of the alimentary canal that the peristaltic action is most active and most distinct. A contraction takes place at a particular spot, by which the intestine is reduced in diameter, its sides drawn together, and its contents forced onward into the next portion of the alimentary canal. This contraction then extends to the neighboring parts, while the portion originally contracted becomes enlarged; so that a slow, continuous, creeping motion of the intestine is produced, by successive waves of contraction and relaxation, which incessantly follow each other from above downward.

The effect of this is to produce a peculiar writhing, worm-like movement among the coils of the intestine, by which the food, while undergoing digestion, is steadily carried forward, so as to traverse the entire length of the small intestine, and to come in contact successively with the whole extent of its lining membrane.

50. **Complete Digestion of Food in the Intestine.**—In this way the complete digestion of the food, and at the same time its absorption, are provided for. For, as the food moves slowly from above downward, those portions which are already digested are removed by absorption through the lining membrane. This leaves the remaining portion of the food more fully exposed to the contact of the digestive fluids, until, toward the lower part of the small intestine, the whole has been thoroughly liquefied and converted into materials fitted for absorption.

Thus, in different parts of the small intestine, the appearance of the alimentary mass is different, according to the stage of the digestive function; and its progress may be seen by examining the alimentary canal during digestion in some of the lower animals. The turbid mixture which passes out of the stomach into the intestine when the animal has been fed upon meat (Fig. 24), contains muscular fibres, separated from each other and more or less disintegrated by the action of the gastric juice. The fat vesicles are but little altered, and there are only a few free oil globules to be seen floating among the other ingredients.

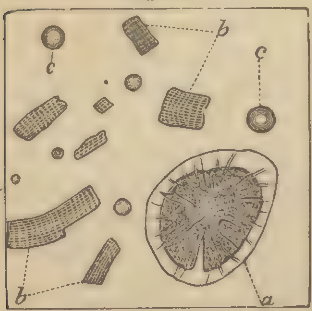
Fig. 24.



Contents of Stomach during Digestion of Meat.—*a*. Fat vesicle filled with opaque, solid, granular fat; *b*, *b*. Bits of partially disintegrated muscular fibre; *c*. Oil globules.

In the upper part of the intestine the muscular fibres are farther disintegrated. They become very much broken up, pale and transparent, but can still be recognized by the granular markings and striations which distinguish their structure (Fig. 25). The fat vesicles also begin to become altered. The solid granular fat of beef becomes liquefied and emulsioned,

Fig. 25.

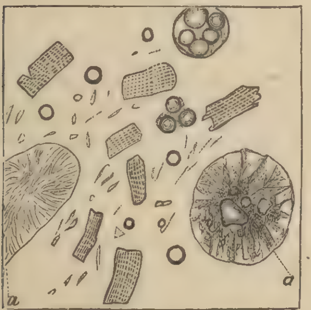


From upper part of Small Intestine.—*a*. Fat vesicle, with its contents diminishing. The vesicle is beginning to shrivel and the fat breaking up; *b*, *b*. Disintegrated muscular fibre; *c*, *c*. Oil globules.

and appears under the form of oil-drops and fatty molecules, and milky chyle shows itself in greater or less abundance; while the fat vesicles themselves are partially emptied, and become, accordingly, collapsed and shriveled.

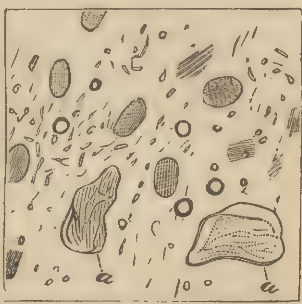
In the middle and lower parts of the intestine (Figs. 26 and 27) these changes continue. The muscular fibres

Fig. 26.



From middle of Small Intestine.—*a*, *a*. Fat vesicles, nearly emptied of their contents.

Fig. 27.



From last quarter of Small Intestine. —*a*, *a*. Fat vesicles, quite empty and shriveled.

become constantly more and more disintegrated, and a large quantity of granular debris is produced. The fat at the same time progressively disappears, and the vesicles may at last be seen entirely collapsed and empty.

In this way the digestion of the different ingredients of the food goes on in a continuous manner, from the stomach throughout the entire length of the small intestine. At the same time, it results in the production of three different materials, viz.: 1st. A solution of albuminous matters, produced by the action of the gastric juice; 2d. An oily emulsion, produced by the action of the pancreatic juice on fat; and, 3d. Sugar, produced from the transformation of starch by the mixed intes-

tinal juices. These substances are then ready to be taken up into the circulation; and as the mingled ingredients of the intestinal contents pass successively downward through the alimentary canal, the products of digestion, together with the digestive secretions themselves, are gradually removed and absorbed by the vessels of the lining membrane.

Thus the food, which is taken into the mouth in the form of bread, meat, fruits, and vegetables, is reduced and transformed by the action of the digestive fluids, until its nutritious ingredients are separated from each other and converted into new materials. The refuse matters which are not digestible, and which can serve no purpose in the nourishment of the body, are at the same time eliminated and rejected. They pass into the large intestine; while the nutritious portions remain behind, ready to be taken up into the current of the circulation.

QUESTIONS FOR CHAPTER IV.

1. What is the object of *digestion?*
2. What is the *alimentary canal?*
3. By what is the food digested in the alimentary canal?
4. In what way is it digested?
5. Name and describe the different parts of the alimentary canal.
6. To what two processes is the food subjected in the *mouth?*
7. What is *mastication?*
8. What are the organs of mastication? What are they composed of, and what are their different parts?
9. How many different kinds of teeth are there, and how many of each in each jaw?
10. What is the situation, form, and use of the *incisors?* of the *canines?* of the *molars?*
11. How are the *movements* of mastication performed?
12. By what glands is the *saliva* produced?
13. At what time is it most abundantly secreted?

14. What is its appearance, and what are its ingredients?

15. How much saliva is produced in twenty-four hours?

16. What are the uses of the saliva?

17. How does the *tongue* assist in mastication?

18. What is the combined effect of the saliva and mastication?

19. At what point does the food pass beyond the control of the will?

20. What is the structure of the *œsophagus?*

21. How is the food swallowed into the stomach?

22. What is the structure of the *stomach?* of its lining membrane?

23. What digestive fluid is produced in the stomach?

24. At what time is the gastric juice secreted?

25. What is the action of the *muscular coat* of the stomach?

26. What is the appearance of the gastric juice, and what are its ingredients? Which is the most important?

27. What effect does the gastric juice have upon the food?

28. Which of the ingredients of the food are dissolved by the gastric juice?

29. In what way does the pepsine act in digesting the food?

30. What *temperature* is required for the action of the gastric juice?

31. What effect does the gastric juice have upon *milk?*

32. Where does the food pass after leaving the cavity of the stomach?

33. What kinds of food are most easily digestible?

34. What are the best methods of *cooking* food?

35. Why is *fried* food apt to be difficult of digestion?

36. Why should vegetables be very thoroughly cooked?

37. Why should the food be taken in *moderate quantity?*

38. Why should it be taken *at regular times?*

39. What effect does *nervous irritation* have on the process of digestion?

40. What digestive fluid is produced by the small intestine?

41. What are the *Follicles of Lieberkühn?*

42. What is the appearance of the intestinal juice?

43. What effect does it have upon the food?

44. What is the appearance of the *pancreatic juice?*

45. By what organ is it produced, and where is it poured into the intestine?

46. What are its ingredients?

47. What effect does it have upon the food?

48. What is the fluid called which is produced by the digestion of the fats?

49. What is its appearance?

50. What is the "*peristaltic action*" of the intestine?

51. What effect does it have upon the food?

CHAPTER V.

ABSORPTION.

Lining Membrane of Intestine.—Valvulæ Conniventes.—Villi.—Endosmosis.—Absorption by Living Membranes.—Influence of the Circulation.—Blood-vessels of the Intestine.—Portal Vein.—Blood of the Portal Vein during Digestion contains Albuminose, Sugar, and Chyle.—Change in its appearance owing to Chyle.—Distribution of Portal Vein in the Liver.—Reabsorption of the Digestive Fluids. — Lymphatic Vessels. — Lacteal Vessels. — Appearance of Lacteals during Digestion.—Receptaculum Chyli.—Thoracic Duct. —Discharge of Digested Matters into the Blood.—Their Transformation and Disappearance.—Nutrition of the Blood.

51. **Absorption of the Food.** — We now enter upon a new chapter in the history of the materials of nutrition. The first stage in their progress toward the nourishment of the body has been passed, and they are now ready to undergo a different action ; for all the changes and modifications which we have thus far studied in the digestion of the food have been simply a kind of preparation for that which is to follow. The digested and nutritious elements of the food are still inclosed in the alimentary canal; and, before they can reach their destination and arrive at the tissues which they are to nourish, they must first pass through its walls and gain entrance into the blood. This process is known by the name of *Absorption.*

How is this passage from the intestine into the blood-vessels accomplished?

52. **Lining Membrane of the Intestine.** — The lining

membrane of the alimentary canal, as we have already said, is of great extent. For not only does it follow the whole length of the tube itself, but in the small intestine it is thrown into a great number of transverse folds or valves, called the *Valvulæ conniventes.* Each valve is formed of a double layer of the lining membrane, folded upon itself at its inner edge like the plaiting of a ruffle; so that all of them, taken together, increase very much its extent of surface. As the small intestine itself measures twenty-five feet in length, the entire extent of its lining membrane, owing to the folds just described, is at least doubled, or not less than fifty feet in all.

This membrane, however, is exceedingly thin, soft, and flexible, so that it is easily contained within the limits of the intestine.

53. **Villi of the Small Intestine.**—But beside this, the lining membrane of the small intestine is beset throughout with a multitude of still more minute elevations, in the form of delicate flattened, conical, or thread-like filaments projecting from its inner surface, which are called the *Villi* (Fig. 28). They resemble the pointed elevations in the pyloric portion of the stomach (p. 98), except that they are longer and more slender in shape. They are so closely set that they give to the surface of the lining membrane a fine velvety appearance, and an exceeding softness to the touch. Each

Fig. 28.

Villi of the Small Intestine, with their blood-vessels; highly magnified.

villus is provided with a network of minute vessels, through which the blood circulates in a multitude of inosculating currents.

These villi are the principal agents of absorption. They hang out freely in the cavity of the intestine, and penetrate every where into the digested material which it contains. They are the rootlets by which the lining membrane absorbs the nutritious elements of the food, just as the roots of a plant absorb nourishment from the soil in which they are imbedded.

54. **The Nature and Method of Absorption.**—But there are no openings in the substance of the villi, which on the contrary present every where a continuous and unbroken surface. How is it, therefore, that the nutritious fluids can find an entrance?

It is owing to a peculiar action manifested by the animal membranes, which enables certain fluids to pass directly through their substance by a kind of transudation or imbibition. This action is known by the name of *Endosmosis.*

Every animal membrane will absorb certain fluids with greater or less facility. If you take a dried bladder and place it in warm water, it will gradually absorb the liquid, and become thickened, moist, and pliable, until it recovers nearly its original appearance and consistency. This will take place usually with any substance formed of an animal tissue, but it does not always happen in exactly the same way. Each animal membrane will absorb some fluids more readily than others. Thus some of them will absorb pure water more abundantly than a solution of salt, or a solution of sugar more readily than one of gum; and the same liquid will be absorbed more readily by one

membrane, and less so by others. Thus every animal membrane has a special power of absorption for certain liquids, which it will take up in greater or smaller quantity, according to their nature and composition. In all cases, however, there is a natural limit to this quantity, beyond which absorption will not continue.

55. **Absorption by the Blood-vessels.**—Now this power is exhibited by the animal membranes much more actively during life than after death; because, first of all, the living membranes are perfectly fresh and unchanged in their structure, and, second, because they are filled with the circulating blood moving incessantly through their vessels. This increases very much the quantity of fluid taken up; because the blood absorbs the new materials from the animal membrane, just as the membrane has absorbed them from the external liquid, and this blood, passing immediately away with the current of the circulation, is followed by a new supply, which takes up in its turn what has accumulated since. Thus the animal membrane is constantly relieved of the fluid which it has already absorbed, and is then enabled to receive a fresh supply; just as a reservoir, which receives water at one extremity and discharges it by a waste-pipe at the other, may be kept constantly full but never running over. Accordingly, the absorbing power of the living membrane is not easily exhausted, but remains in full activity so long as the blood continues to perform its work.

It is in this way that the digested fluids are conveyed from the intestine into the blood-vessels. The liquid albuminose from the stomach, and the sugar produced from the digestion of starch, are both dissolved in the fluids of the alimentary canal, and are thus made ready

for absorption. Even the oily substances of the chyle are capable, in their minutely disintegrated form, of penetrating the substance of the villi, and of entering their blood-vessels. For it is found that the fine particles of a milky emulsion may be absorbed by an animal membrane, although the oil in its natural condition can not pass through its substance. And, in point of fact, if the villi from the small intestine, during digestion, be examined by the microscope, they are found to be turgid with chyle, and penetrated every where with its minute oily particles. Thus all the materials of the digested food are taken up by the villi of the alimentary canal. From the villi they pass directly onward into the blood.

56. **The Portal Vein and Circulation through the Liver.**—The course of the blood-vessels, which after passing through the walls of the intestine return from them to the heart, is a peculiar one, and merits a particular description. We have already seen that each one of the intestinal villi is filled with a network of minute vessels. These vessels terminate at the base of each villus in a little vein, which receives the blood coming from it, and unites with other similar veins returning from the adjacent parts of the intestine. The branches so formed unite with still others coming from more distant regions, like so many different roads all joining a common highway. In this manner, the veins, returning from all parts of the intestine, are at last collected into a single great trunk, which is known by the name of the *Portal Vein.* The portal vein therefore contains all the blood which has traversed the lining membrane of the intestinal canal, together with the substances which it has absorbed from the intestinal cavity.

Accordingly, the blood circulating in the portal vein, while digestion and absorption are going on, is charged with the nutritious materials of the food. It contains the digested albuminous matters under the form of albuminose, and the sugar produced by the digestion of starch. It contains also the oily substances of the chyle mingled with its other ingredients. This gives to the blood of the portal vein, during digestion, a peculiar aspect. For while the sugar and albuminous matters, being in a state of solution, can not be distinguished by the eye and are only to be recognized by their chemical tests, the oily granules of the chyle, being simply suspended in the blood, consequently alter its color and appearance, and may be easily distinguished by the microscope. The blood of the portal vein, therefore, at this time is rich in oleaginous granules; and when it coagulates, its watery parts are turbid and whitish in color, and a thin milky pellicle rises to the surface. In the intervals of digestion, on the contrary, the watery parts of the portal blood are clear and transparent, like that from any other region of the body.

The portal vein, conveying the blood thus loaded with nutritious materials, passes upward through the cavity of the abdomen until it reaches the situation of the liver.

Here, however, instead of continuing its course directly toward the heart, it passes into the substance of the liver, where it undergoes a very singular distribution. It is on this account that it has received the name of the "portal" vein, because it enters the liver by a kind of fissure or "gateway" upon its under surface. Once within the substance of the organ, it divides right and left into two great branches, which penetrate

the two opposite sides of the liver; and then, dividing still into smaller and more numerous ramifications, its branches at last reach the little glandular lobules of which the whole organ is composed. Here they finally break up into a plexus of minute vessels, as fine as those which originally occupied the substance of the intestinal villi, and which fill the entire substance of the liver with a similar vascular network.

Beyond the glandular lobules of the liver, the blood-vessels again collect into little veins, and those from the neighboring lobules unite into larger branches, like those from the adjacent villi of the intestine. Now, however, the veins so formed are called the "hepatic veins;" and by repeated junction, those coming from all parts of the liver are at last united into one common Hepatic Vein. This vein soon afterward discharges its blood into the great venous current returning directly to the heart.

Thus the blood which has circulated through the lining membrane of the intestine, and which has there absorbed the digested materials of the food, is compelled to pass through another set of inosculating vessels before returning to the heart. Arriving at the liver by the portal vein, it is there distributed through all the vascular channels of the organ, and comes into contact every where with the substance of its lobules. We shall see hereafter what important changes take place while the blood is thus pursuing its course through the depths of the glandular tissue. Having accomplished this passage, however, and still bringing with it the nutritious materials of digestion, it arrives at the heart by the great veins of the abdomen. Here it finally discharges its load into the general mass of the circulating blood.

57. **Reabsorption of the Digestive Fluids.**—But at the same time that the elements of the food are thus taken up from the intestine and conveyed into the blood, the intestinal juices themselves are also absorbed and returned to the blood from which they came. For it is the blood which originally furnished all the materials for the digestive fluids. The saliva, the gastric juice, the intestinal juice, the pancreatic juice, are produced by the glandular organs and the lining membrane of the alimentary canal, as we have already described; but they are produced at the expense of the blood, which necessarily supplies the requisite nourishment for all the organs of the body.

Now these digestive fluids are secreted in large quantity. Taken altogether, not less than twenty pounds of animal juices are poured into the alimentary canal every day for the digestion of the food. If this quantity were simply drained away from the blood, it would prove utterly exhausting to the animal frame. The digestion of the food would cost more, so to speak, in the waste of the digestive fluids, than it would return to the body in the form of nourishment.

But none of these fluids are lost. They are all taken up again by the vessels of the lining membrane, together with the elements of the food which they have served to digest. What the blood-vessels absorb, therefore, is not simply the nutritious elements of the food, but these nutritious elements dissolved in the digestive fluids. The albuminous matters, when transformed by the pepsine, are at once liquefied in the abundant gastric juice; the sugar is dissolved also in the intestinal fluids; and the chyle, as we have seen, is really an emulsion of the fatty particles in the albuminous liquid

of the pancreatic juice. All these substances, digestors and digested, are finally absorbed at the same time by the blood-vessels of the alimentary canal.

The digestive fluids, accordingly, perform a sort of circulation; passing from the blood to the intestine, and from the intestine back again to the blood. They are the messengers, sent out by the blood to collect the nutritious elements in the alimentary canal, and then to return with them into the current of the circulation.

58. **Absorption by the Lacteals.**—But the absorption of the food is also accomplished in part by another set of vessels, differing from those which we have heretofore described. These vessels are the *Lacteals.*

The lacteals are simply part of a great system of vascular channels distributed throughout the body, which are called the "Lymphatic" or "Absorbent" vessels. In the skin, the muscles, the internal organs, the lining membranes, they begin by a fine network, imbedded in the tissues, and then collect into small branches which run upward and inward toward the great cavities of the chest and abdomen. They finally terminate in the veins. Those coming from the right arm and the right side of the head and neck empty into the veins of this part of the body. Those from the legs and thighs pass into the cavity of the abdomen, where they are joined by others coming from the loins, the kidneys, the spleen, the liver, stomach, and intestine. All these collect into a single tube or duct, not more than a quarter of an inch in diameter, which then mounts from the abdomen into the chest, and runs upward along the spinal column. This tube is called the "Thoracic Duct." It at last rises from the chest into the lower part of the neck, and then, curving forward, terminates in the

great subclavian vein, not far from the region of the heart (Fig. 29).

Now these vessels are incessantly engaged in absorption. They take up constantly, from all parts of the body where they are distributed, a transparent and colorless liquid, which is termed the "lymph." It is on this account that they have received the name of lymphatics. The lymph represents a portion of those ingredients of the tissues which have become useless, and which must be restored or renovated before they can again take part in the functions of life. They are therefore taken up by the lymphatic vessels and conveyed back toward the heart, there to be mingled with the current of the venous blood.

The lymphatic vessels are not readily distinguished by the eye. First, because they are very small in size, and their walls exceedingly thin and delicate; and, secondly, because the lymph which they contain is colorless and transparent. The blood-vessels we can easily see, even when their walls are thin, owing to the red color of the blood which they contain; but there is nothing to distinguish the course of the lymphatics, since both their walls and their contents are equally colorless. They are therefore easily overlooked, unless we take especial pains to search for them among the other tissues.

The lymphatics of the intestine are exactly like those of other parts of the body. They commence in the villi and in the substance of the lining membrane, and then pass inward to join those coming from other organs. Usually they are almost invisible like the rest, for they contain only the transparent lymph, as we have already described. But when the digestion of the food is in full activity they also begin to take up the oily particles

from the cavity of the intestine. They become turgid with chyle, and then, enlarged and distended with this milky fluid, they at once become visible to the eye as white rounded filaments, showing through the transparent coverings of the intestine. They are then called the "lacteals," from their white color and the milk-like appearance of the fluid which they contain.

The intestines, folded upon themselves in many turns, as we have already described them, are loosely attached to the spinal column by a broad sheet of thin membrane, like the band of a ruffle, which is called the "mesentery." Through this sheet the lacteals pass from the intestine toward the back part of the abdomen; and there, just before mounting into the chest, they unite into a little cavity or sac, which is called the "receptaculum chyli," or "receptacle of the chyle," situated just at the commencement of the thoracic duct (Fig. 29).

Accordingly, the absorbent vessels of the abdomen have a very different appearance at different times. In the intervals of digestion they are nearly invisible, for they are then merely lymphatics, and contain only a colorless fluid. But during digestion they present themselves as an abundance of fine white glistening ducts, converging every where from the folds of the small intestine, and uniting with each other at the receptaculum chyli. Thence the chyle is carried onward through the thoracic duct and is discharged at last into the blood of the subclavian vein. When the process of digestion is terminated, and all the chyle has been exhausted from the cavity of the intestine, the lymphatics of the abdomen return to their former condition, and become again colorless and invisible as before.

Fig. 29.

Lacteals and Lymphatics.

Thus the chyle produced during digestion is conveyed into the circulation by two different routes. First, by the blood-vessels of the intestine, through the portal vein and the liver, to the hepatic vein; and, secondly, by the lacteals and the thoracic duct to the subclavian vein. It is, accordingly, all finally mingled with the blood returning to the heart.

59. **Changes in the Food after it is Absorbed.**—The history of absorption is not yet finished.

Thus far we have seen how the substances produced by digestion are taken up from the intestinal canal and mingled with the circulation. But they are not yet ready for nutrition, since they are still different from the natural ingredients of the blood. The albuminous matter

formed in digestion is not the same with the albumen of the blood. Sugar also is a substance which is not to be found in the blood-vessels generally; and the milky chyle, so abundant in the portal vein during digestion, is not an ordinary ingredient of the circulating fluid. These substances, therefore, must be still farther modified and transformed before the nutrition of the blood is complete.

This transformation is accomplished in the blood-vessels. Soon after entering the circulation, the albuminose, which was absorbed by the intestinal veins, disappears and is replaced by the natural albumen of the blood. This is a metamorphosis or conversion, similar to that by which the albuminose was itself produced by the gastric juice in digestion. The other ingredients of the circulating fluid act upon it by catalysis, and change it into the substance necessary for the composition of the blood.

Thus the albumen of the blood is finally recruited from the nutritious elements of the food. But it is only after these have undergone a double transformation; first into albuminose by the influence of the gastric juice in the stomach, and secondly into albumen by the influence of the blood itself in the interior of the vessels.

The sugar and the oily matters also disappear soon after they are received into the circulation. We do not know exactly what becomes of them; but they are amalgamated in some way with the natural ingredients of the blood, and thus serve at last for its nutrition.

60. **Periodical Excitement of the Digestive Apparatus.** —Finally, the whole process of digestion and absorption is accompanied by a remarkable excitement and congestion of the alimentary canal. We have already seen

how the lining membrane of the stomach becomes filled with blood when the food is taken into its cavity. The same thing happens with the small intestine. During the act of digestion its lining membrane becomes thickened and more vascular, at the same time that the peristaltic movement of its walls is called into activity. While absorption is going on, also, its vessels are loaded with the nutritious fluids absorbed from its cavity, and return to the heart a larger quantity of blood than at other times. This continues until the process of digestion is complete, and until all its new materials have been distributed throughout the circulation. Then the unusual excitement and activity of the alimentary canal gradually subsides. Its walls become paler and softer; its muscular contractions grow less frequent and active; and, finally, the whole intestine is restored to its ordinary condition of repose.

QUESTIONS FOR CHAPTER V.

1. What is *absorption?*
2. What are the *valvulæ conniventes* of the small intestine?
3. What are the *villi* of the small intestine?
4. What is the function of the villi?
5. What is *endosmosis*, and how is it regulated?
6. How does the circulation of the blood assist in absorption?
7. How are the blood-vessels arranged in the villi?
8. Into what vein do they empty?
9. What does the blood of the portal vein contain during the digestion of the food?
10. To what organ is the blood conveyed by the portal vein?
11. After passing through the liver, whither is the blood conveyed?
12. What becomes of the *digestive fluids* during the digestion and absorption of the food?
13. What are the *lymphatic* or *absorbent* vessels?
14. Where do they originate and where do they terminate?
15. In what duct do the lymphatics of the abdomen terminate?

16. Where does the thoracic duct communicate with the veins?

17. What is the general appearance of the lymphatic vessels, and of the lymph which they contain?

18. What is the appearance of the lymphatics of the intestine during digestion, and why are they then called "lacteals?"

19. By what two routes is the chyle conveyed into the circulation?

20. What changes take place in the elements of the food after their absorption?

21. How is the circulation in the alimentary canal changed during digestion, and what is its condition after digestion is finished?

CHAPTER VI.

THE LIVER AND ITS FUNCTIONS.

Situation and Structure of the Liver—its Lobules.—Biliary Ducts.—Secretion of the Bile.—Gall-bladder.—Accumulation of Bile in the Gall-bladder—its discharge into the Intestine.—Appearance and Composition of the Bile.—Biliary Salts.—Mode of extracting them from the Bile.—Their Crystallization.—Changes of the Bile in the Intestine—its absorption by the Blood.—Function of the Bile.—Formation of Sugar in the Liver—its absorption by the Blood-vessels.—Sugar finally decomposed in the Circulation.

From what we have already learned, it is evident that the liver plays a prominent part in regard to the process of absorption. Placed in the immediate neighborhood of the digestive organs, and united with them by various anatomical connections, it is, to some extent, associated with them in function. It is also the great highway through which the blood passes in its course from the intestine to the heart, and where it undergoes certain changes of the greatest importance.

61. **Situation and Vascularity of the Liver.**—The liver is a large and solid organ, placed in the upper part and on the right side of the abdomen, a little above the level of the stomach. If we place the open hand over the lowermost ribs of the right side of the body, it will almost exactly cover the situation of this organ. It receives, as we have seen, the portal vein, which ramifies extensively in its substance. It is also supplied with an artery; but this artery is comparatively of small

size, and by far the larger portion of the blood which circulates in the liver comes from the branches of the portal vein.

The first and most well known function performed by the liver is the production of the *Bile*.

62. **Structure and Secretive Function of the Liver.**—If we examine the minute structure of the organ, we find that it is composed of a great number of small rounded granular masses, closely packed together, which are called its "lobules." It is into the substance of these lobules that the minute blood-vessels penetrate, and form there a fine vascular network.

But beside these blood-vessels there is another set of tubes, equally delicate, which commence in the substance of the lobules and join each other in the spaces between them. They then unite into branches like those of the veins, and, continuing their course from the deeper parts of the organ, finally emerge at the great fissure or gateway at its under surface. These little tubes are called the "biliary ducts."

The liver is accordingly drained throughout its substance by a multitude of fine ducts or canals, like the ditches of a cultivated field; only these ducts are of minute size and disseminated every where throughout the organ, collecting at last into a main tube or sluice-way at its surface.

Now in the interior of these ducts there appears a watery fluid, of a rich brownish-yellow color and a bitter taste, containing many different ingredients of a peculiar nature. This fluid is the *Bile*. It is formed in the interior of the lobules, and is taken up from them by the little canals in their tissue. As it accumulates in the smaller ducts it fills the larger branches also, and is thus

conducted into the main channel at the under surface of the organ.

How is it that the bile is formed in the substance of the lobules?

This is another example of that singular transformation of which we have already seen so many instances. None of the more important ingredients of the bile are to be found in the blood; and yet the blood is the only source from which the liver derives its nourishment. But, as the lobules absorb from the blood its nutritious elements, and fix them in their own substance, they at the same time transform or change some of them into other materials. We can not explain more fully the manner in which this takes place; we only know that this is a property belonging to the tissue of the lobules, just as it is the property of the gastric juice to change the albuminous substances in digestion. It is thus that the peculiar ingredients of the bile, giving it its bitter flavor, its yellow color, and its other important properties, make their appearance in the interior of the liver.

The liver is therefore a kind of manufactory in which a new fluid is produced, differing from the blood by which its materials are supplied.

From the great fissure upon the under surface of the organ the main biliary duct passes downward to the small intestine, which it reaches at the distance of a few inches from the pylorus (Fig. 18, *f*). Here it penetrates the wall of the intestine, and opens into its cavity by a small orifice on the inner surface of the lining membrane.

Thus the bile, first produced in the liver, is conveyed downward by the biliary duct, and finally discharged into the upper part of the small intestine.

But about midway between the liver and the intestine the biliary duct communicates with a membranous sac or bag, which is called the *Gall-bladder*. It is a rounded, pear-shaped bag, about three inches in length, attached to the under surface of the liver. It can be easily recognized, both in man and in most of the animals used as food, by its form and situation, and by its being filled with dark liquid bile. The bile, in fact, accumulates in the gall-bladder as in a kind of reservoir. A portion of it always passes downward through the biliary duct, and is discharged at once into the intestine; but a portion is also turned back into the gall-bladder, especially in the intervals of digestion, and is there stored away for future use. The longer the time which has elapsed since digestion, the greater the quantity of bile which accumulates in the gall-bladder. Consequently, this organ varies very much in size at different times. Immediately after digestion it is small and collapsed; but if examined after one, two, or three days of fasting, it is found full of bile, and increased to two or three times its former dimensions.

Beside, the bile which is contained in the gall-bladder is somewhat different from that which is still in the biliary ducts. In the ducts within the substance of the liver it is thin, watery, and yellowish. In the gall-bladder it is thicker, darker colored, and viscid in consistency. While retained in the gall-bladder, therefore, it suffers a certain change; and this change is principally due to a viscid substance or "mucus," which is secreted by the gall-bladder, and mingled with the bile which it contains.

63. **Physical Appearance and Ingredients of the Bile.**—Owing to the accumulation of the bile in the reservoir

of the gall-bladder, we can easily obtain it for examination.

As it comes from the gall-bladder, the bile is a rather viscid fluid of a golden-brown color, which often varies through many different shades of yellow and green. If we shake it up in a closed vessel with air, it becomes very frothy and soapy in appearance, entangling the bubbles of air, which adhere closely to each other and to the surface of the fluid.

The ingredients of the bile are, first, water; secondly, certain substances of an animal nature, combined with soda, which are its most peculiar elements, and which are therefore called the "Biliary salts;" thirdly, a coloring matter, which gives to the bile its greenish or brownish hue; fourthly, substances of a fatty nature; and, lastly, mineral ingredients. Mingled with these, as we have already mentioned, there is usually a small quantity of mucus from the lining membrane of the gall-bladder.

The proportion of these ingredients is as follows:

Composition of the Bile in 1000 parts.

Water	880.00
Biliary salts	90.00
Coloring and fatty matters	13.42
Mineral ingredients	15.24
Mucus of the gall-bladder	1.34
	1000.00

Of all these ingredients, those which are called the "Biliary salts" are the most important. They may be extracted from the dried bile by pure alcohol, since they are soluble in this fluid, and are thus separated from other impurities which remain behind. But if ether be afterward added to the alcoholic solution, the biliary salts separate from the mixture, and are then

slowly deposited in a crystalline form. The crystals are at first very minute and of various shapes. Afterward they gradually increase in size, until they sometimes become visible to the naked eye (Fig. 30).

Fig. 30.

Crystals of the Biliary Salts, from human bile; magnified 25 times.

The *entire quantity* of the bile which is secreted during the day varies in different kinds of animals. As a general rule, it is more abundant in those which live upon vegetable food than in those which are carnivorous. In man, the best calculations show that the daily quantity of bile is about two pounds and a half.

64. **Function of the Bile in the Intestine.**—What purpose does the bile serve in the alimentary canal?

This is not an easy matter to decide; for, notwithstanding the abundance of the bile and its remarkable characters, its ingredients are so different from those of the other secretions, and its functions are so obscure, that this has been found one of the most difficult of all the questions connected with the digestion and absorption of the food. What has been really learned in regard to it is as follows:

First of all, the bile is secreted and poured into the alimentary canal at all times. It is not like the gastric juice, which is produced only during the period of digestion; but it is incessantly formed by the liver, and is continually discharged into the intestine by the biliary duct. It is always to be found, therefore, in greater or less quantity, in the cavity of the alimentary canal,

where it can be easily recognized by its yellow color, and by the chemical tests which are employed to detect it.

Nevertheless, it is poured into the intestine more abundantly at the beginning of digestion. At this time, and within a few minutes after the food is taken into the stomach, the commencing excitement of the whole digestive apparatus is communicated to the gall-bladder. Its muscular fibres contract, and it thus discharges the bile which has accumulated within it into the upper part of the small intestine. It is for this reason that the gall-bladder is found empty soon after digestion, and again distended with bile when a long interval has elapsed.

But, after the gall-bladder is emptied, the liver still continues its activity of secretion, and the bile which it produces is still conveyed into the intestinal cavity.

Here, however, it gradually disappears. Abundant in the upper part of the small intestine, it is less so in the middle and lower parts, and, finally, it is no longer to be recognized either by its color or by its chemical tests. These tests also show that it is not discharged from the body. It is therefore withdrawn from the alimentary canal, and taken up by the blood-vessels at the same time with the digested elements of the food.

But before being absorbed from the cavity of the intestine it is changed. Its peculiar ingredients, the biliary salts, are transformed into other materials by the influence of the intestinal fluids, and are then conveyed into the current of the circulation.

We do not know what these new materials are, but we know that they are necessary to life; for if the bile be not secreted, or if it be prevented from entering the

intestine, the animals so affected die enfeebled and emaciated.

Thus the bile passes through the alimentary canal, not for the purpose of assisting in the digestion of the food, but in order that its own ingredients may be changed and converted into other substances. The blood needs these substances for its nutrition, and they are accordingly produced by means of the biliary secretion.

This is accomplished, again, by a double transformation. As the muscular flesh of our food is converted first into albuminose by the stomach and afterward into albumen in the blood-vessels, so certain of the elements of the blood are transformed by the liver into the salts of the bile, and these again are changed in the intestine into new materials, which are finally absorbed by the blood-vessels of its lining membrane.

65. **Formation of Sugar in the Liver.**—Beside the formation of the bile, the liver performs also another and very important office; that is, the production of *sugar.*

We have seen that when starch is taken with the food it is changed into sugar by digestion, and this sugar is absorbed by the blood-vessels and thus carried into the circulation. But there are many animals who never take any starch or sugar with their food. Such are all the carnivorous animals—that is, those who live entirely upon the flesh of other animals. Their food contains no vegetable substances, and consequently has no starchy ingredient.

Now it is a very curious fact that in these animals the substance of the liver always contains sugar. Even when they have kept for many weeks or months upon no other food than animal flesh, sugar is still found in

the tissue of the liver. Furthermore, no other organ in the body contains this substance, and even the blood with which the liver is supplied is equally destitute of it.

Therefore it is the liver itself which forms the sugar, in these cases, out of other materials. It would be too long a history to describe all the ingenious and careful experiments by which physiologists have arrived at this conclusion; but there is now no doubt that in the carnivorous animals sugar really makes its appearance in the liver, when no such material has been taken with the food.

The same thing is true of man, and of the herbivorous or vegetable-feeding animals. For in them also the liver contains a certain proportion of sugar, no matter what may be the nature of the food consumed; and this proportion is often greater than that which could be produced in the digestive process.

The sugar thus produced is formed in the solid tissue of the organ itself. This tissue absorbs the nutritious materials from the blood, and then transforms a part of them into a saccharine ingredient. The same tissue, as we have already seen, also contains the elements of the bile; and it is for this reason that the livers of certain animals, when cooked for food, have at the same time a bitter and a sweet taste.

66. **Absorption and Decomposition of the Liver-sugar.** —But the sugar, when once formed, does not remain in the liver. It at once begins to be absorbed by the blood-vessels of the organ, and so, entering the circulation, passes onward with the blood of the hepatic veins toward the heart. Thus, in many cases, the blood of the portal vein coming to the liver contains

no sugar; while the blood of the hepatic veins, going away from it, is charged with this substance which it has absorbed from the tissue of the organ in its passage.

Soon afterward, the sugar disappears entirely. We have already seen how that which is produced by digestion is finally decomposed in the circulation; the same thing happens with that which is absorbed from the liver. None of it is to be found in the blood of the general circulation.

In the liver, therefore, there are produced two different substances, which pass away in two opposite directions: First, the bile, which is absorbed by the biliary ducts, and conveyed downward to the intestine; and, secondly, the sugar, which is absorbed by the blood-vessels, and passes upward to the heart. In either case, these secretions are afterward decomposed into new substances, which finally take their place as ingredients of the circulating blood.

QUESTIONS FOR CHAPTER VI.

1. What is the situation of the *liver?*
2. What is the principal vessel which supplies it with blood?
3. What is the principal secretion produced by the liver?
4. What are the *lobules* of the liver?
5. What ducts originate from the substance of the lobules?
6. Where does the bile first make its appearance in the liver?
7. How do the lobules produce the ingredients of the bile?
8. Where is the bile conveyed by the main biliary duct?
9. What is the situation and form of the *gall-bladder?*
10. What is its use?
11. At what time does the bile accumulate in the gall-bladder?
12. How is it changed while remaining in the gall-bladder?
13. What is the consistency of the bile? its color?
14. What are its ingredients? which are the most important?
15. How may the biliary salts be extracted from the bile?

16. Is the bile more abundant in carnivorous or in herbivorous animals?

17. How much is produced in man during twenty-four hours?

18. Is the bile secreted *occasionally* or *constantly?*

19. At what time is it poured into the intestine most abundantly?

20. What becomes of the bile after it is poured into the intestine?

21. What other substance is produced in the liver beside the bile?

22. How do we know that sugar is formed in the liver?

23. What becomes of the sugar produced by the liver?

CHAPTER VII.

THE BLOOD.

Ingredients of the Blood.—Water.—Salt.—Lime.—Albumen.—Properties of Albumen.—Fibrine—its Properties.—Blood Globules—their Form—Size—Color—Consistency.—White Globules.—Quantity of different Ingredients in the Blood.—Coagulation of the Blood.—Clot.—Serum. Coagulation dependent on the Fibrine.—Use of Coagulation in stoppage of Bleeding.—Why Blood does not Coagulate in the Vessels.—Daily Production and Decomposition of Fibrine.—Entire Quantity of Blood in the Body—its Variation.—Variation in Composition of the Blood.—Two different Kinds of Blood in the Body.

We now come to the study of that remarkable fluid which contains all the materials necessary for nutrition, and provides for the common support of the whole body. Nourished itself by the elements of the digested food which it has absorbed from the intestine, it compels them to assume a new form on entering the blood-vessels, and converts them into its own ingredients. Thus it is constantly maintained in a healthy condition by the incessant supply of new materials.

All the processes, therefore, of digestion and absorption are subservient to the nutrition of the blood.

67. **Physical Appearance and Composition of the Blood.**—The blood is a thick opaque fluid, of a rich deep red hue, so peculiar that it may usually be distinguished by its color alone. It contains many different ingredients, of which the most important are, first, *Water;*

second, *Mineral substances;* and, third, *Albuminous matters.*

The water of the blood is what gives it its fluidity. For if the water be driven off by evaporation, the other ingredients remain behind in the form of a dry mass, which would be entirely useless for the purpose of nutrition. But in its natural condition the water of the blood unites all its other ingredients into a uniform liquid, which easily moves through the blood-vessels, and dissolves the new substances which are absorbed from without. Taken altogether, the water forms rather more than three fourths of the whole mass of the blood.

The mineral ingredients are in much smaller proportion. The most abundant is common *salt*, which we know is taken with the food, and is a necessary ingredient of all the tissues. It forms, however, only about four parts in a thousand of the whole blood. The combinations of *Lime*, which the bones and teeth require for their nourishment, are found in still smaller quantity, dissolved in the animal fluids of the blood. Other mineral substances of various kinds are also present in their requisite quantity.

But the most remarkable of all the ingredients of the blood are its albuminous matters. It is these substances which give to it its thick and animal consistency, and which also act the most important part in the nutrition of the body. They are of two different kinds, which are naturally mingled together in the blood in a liquid form.

The first of these is the *Albumen.* We can obtain a tolerably correct idea of the characters of albumen from the fresh white of egg, which has received a simi-

lar name. This is not exactly the same thing with the albumen of the blood, but still the two resemble each other very closely. They may both be coagulated by boiling, when they become solid, white, and opaque. The principal difference between them is, that the fresh white of egg is partly gelatinous in consistency, while the albumen of the blood is perfectly fluid, and may readily be made to flow through the veins, or to run from one glass vessel into another.

The albumen is about forty parts in a thousand, or one twenty-fifth of the whole blood. It represents, in great part, the concentrated nourishment derived from the food, for it is probably into this substance that most of the albuminose is converted after being absorbed from the intestine in the digestive process. It is the material out of which the tissues of the body are afterward formed.

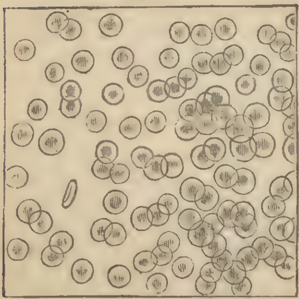
The other animal matter in the blood is the *Fibrine.* Although this is in very small quantity, viz., only two parts in a thousand, it is an exceedingly curious and important ingredient. For it possesses a property which does not belong to any other animal substance, viz., the property of "spontaneous coagulation"—that is, it will coagulate by itself, without being boiled or brought in contact with an acid, or treated by any other chemical substance. We shall see hereafter what an important character this property gives to the blood.

But these substances are only the liquid portions of the blood. They are all dissolved in each other, and form a perfectly transparent and almost colorless fluid. Beside them there are a multitude of little rounded bodies contained in the liquid mixture, which make the

blood opaque, and give to it its red color. They are so abundant that they are crowded together by thousands in each drop of blood, and so minute that they are only visible by the aid of the microscope. They are called the *Blood Globules.*

68. **Globules of the Blood.**—If we examine a drop of blood under the microscope, we see the blood globules floating in profusion in the fluid parts. Each one is a delicate circular plate or disk, somewhat like a piece of money in form, only with the edges rounded and rather thicker than the central part. In human blood they are about $\frac{1}{3000}$ of an inch in diameter when measured across their flat surfaces, and about $\frac{1}{16000}$ of an inch in thickness (Fig. 31).

Fig. 31.



Blood-globules; highly magnified.

The blood globules are exceedingly soft and flexible in consistency. In fact they are nearly fluid, like drops of very thick oil or honey, only they do not dissolve in the other parts of the blood, but retain their own form and substance. Consequently, when moving about in the fluid, as they often do under the microscope, following accidental currents in the blood, passing through narrow channels, and turning corners among the other globules, they may be seen to twist about, and bend over, and elongate in various ways, and then resume their natural figure as before. This peculiar semi-fluid and flexible consistency is one of their greatest peculiarities.

When seen by transmitted light and in thin layers,

they are of a very pale amber color and nearly transparent. Nevertheless they contain all the red color of the blood; and when seen heaped together in layers only five or six deep, they show distinctly the ruddy color which belongs to them. Beside, if they are separated by filtration or any other means, or if they are not formed in their natural quantity, the blood becomes paler, exactly in proportion as its globules are deficient.

They also communicate to the blood its opacity. Although each globule by itself is transparent, yet, when they are crowded together and mingled with the fluid parts of the blood, the whole becomes opaque and apparently impenetrable to light. This is because the globules of the blood and its fluid parts are of a different nature and composition. The same thing will happen when oil is emulsioned by a watery alkaline solution. The oil is transparent by itself, and the alkaline liquid is transparent by itself; but if you mix the two together, the whole becomes white and opaque like milk. So the globules of the blood and its fluid parts, mingled together, produce a thick red and opaque liquid.

The red globules are the vivifying elements of the blood. They communicate to it its animating and stimulating properties, by which all the organs are maintained in a condition of vital activity. We shall understand their action more fully when we come to study the whole subject of respiration and circulation. We shall then see what is the precise function of these globules, and how important an office they perform.

Beside the red globules, the blood contains other little bodies of a different form and aspect. These are

the *white globules.* They are very much less numerous than the red, as there are not more than three or four of them for every thousand of the others. They are of a little larger size, measuring about $\frac{1}{2500}$ of an inch in diameter, of a rounded form and a finely granulated texture. They are usually concealed, for the most part, in the greater abundance of the red globules.

When the ingredients of the blood are examined by analysis, they are found to be mingled together in the following proportions:

COMPOSITION OF THE BLOOD IN 1000 PARTS.

Water	795
Globules	150
Albumen	40
Fibrine	2
Other animal matters	5
Mineral substances	8
	1000

69. **Coagulation of the Blood.**—Such are the properties and constitution of the blood while circulating in the interior of the body. But if it be withdrawn from the vessels, a very remarkable change takes place, which alters its whole appearance.

This change is its *Coagulation.*

When a patient is bled from the arm, or is accidentally wounded, the blood runs from the opened vein in a perfectly liquid stream; but soon afterward it begins to appear thicker than before, and will not run in drops, nor moisten the fingers so easily when touched. When this alteration has once commenced, it goes on rapidly increasing, the blood growing thicker and thicker, until it finally sets into a uniform, firm, elastic, jelly-like mass. It is then said to be "coagulated" or "clotted." This

change is usually complete in about twenty minutes after the blood has been withdrawn from the veins.

Now this coagulation of the blood is entirely dependent upon its fibrine. This substance alone has the property of coagulating spontaneously. None of the other ingredients can solidify in this way, and if the fibrine be taken out, the blood loses altogether its power of coagulation.

But how is it that the whole blood becomes clotted in a single mass, if this power belongs only to the fibrine?

It is because the fibrine, though in very small quantity, as compared with the other substances in the blood, is diffused uniformly throughout the whole; and when it coagulates, therefore, on being withdrawn from the vessels, it entangles all the other ingredients with it, and holds them imprisoned in its own substance. The water of the blood, accordingly, the albumen, the globules, etc., are all mechanically retained by the coagulating fibrine.

But not long afterward a partial separation takes place between them. The fibrine solidifies still more; and, by contracting upon itself, squeezes out the liquid portions of the blood from between its meshes. Drops of a clear, amber-colored fluid begin to exude from its surface, and these drops, growing larger and larger, run together into little pools, which still increase in size until the entire surface is covered with the transparent liquid. The remainder grows at the same time smaller and firmer, until at last the whole is permanently separated into two parts, a solid and a liquid. The solid part is called the *Clot;* the liquid part is the *Serum.*

If you examine, therefore, a cupful of blood at the end of twelve hours after it has been drawn from the veins, you will see that it is no longer a uniform mass, but appears as a solid clot floating in the transparent serum. The clot, at this time, is still firm, red, and opaque, since it contains all the globules of the blood as well as the fibrine. For these globules can not escape from the clot, owing to their form and size, and are therefore retained by the meshes of the coagulated fibrine. The serum, on the other hand, is transparent, and nearly colorless. It contains all the albumen, the water, and other substances dissolved in them.

70. **Importance of Coagulation.**—Now this coagulation of the blood is a property of the greatest importance; for it is the only thing which prevents our bleeding to death after the slightest incision or injury to the blood-vessels. Whenever these vessels are opened by an accidental cut in the skin or in the muscles, the blood at first flows with great freedom, according to the size of the wound. But if we press firmly upon the injured part with a bandage or with the fingers, and then, after a short time, remove the pressure, we find that the bleeding has stopped altogether. This is because the thin layer of blood between the edges of the wounded vessels has coagulated and blocked up the opening. No matter how thin this layer may be, it still coagulates; for every particle of the blood, however small, contains its due proportion of fibrine, and consequently solidifies at the proper time. The clot thus formed adheres to the edges of the wounded parts, and so acts as a continuous bandage or plug, until the tissues have again grown together and become permanently united.

It is in this way that the bleeding from all ordinary wounds is usually arrested by nature. No matter how freely the blood may flow at first, if you keep the parts steadily compressed for twenty minutes or half an hour, the fibrine will then be coagulated and the bleeding will stop.

But when the wound is very deep, or when any of the principal arteries have been severed, this means will not succeed; for the blood comes with so much force from these larger vessels that it can not be kept back by ordinary pressure, and no time is allowed for its permanent coagulation. Then we must call for the assistance of the surgeon, who is often compelled to search for the blood-vessels in the deeper parts of the wound, and to tie up their open mouths with a fine cord or ligature. Why this operation is successful requires a farther explanation.

71. **Coagulation in the Interior of the Body.**—It is a curious fact that the blood will coagulate, not only when it is discharged externally, but also even in the interior of the body, *whenever it is withdrawn from the ordinary course of the circulation.* Thus, if we receive a bruise, and the little vessels beneath the skin are torn, the blood which flows from them coagulates in the neighborhood of the injury. Any internal bleeding produces, after a time, a clot in the corresponding situation where the blood is effused. After death, also, coagulation takes place in the cavities of the heart and in the great veins near it; and whenever any part of the body is so injured as to stop its circulation, the blood necessarily coagulates in its vessels.

Accordingly, when the surgeon places a ligature upon a wounded vessel, he stops the circulation through it.

The blood is imprisoned in the neighborhood of the ligature, and soon afterward coagulates and blocks up the cavity of the vessel with its solidified fibrine. After a time the ligature separates and is thrown off, and the wounded parts unite by the healing of the tissues.

We see, therefore, that the coagulation of the blood is a property that belongs to the fibrine, and that it is spontaneous. As soon as the fibrine is formed it possesses this property, by which it is distinguished from all other substances. It is not manifested immediately, for it requires a certain time for its completion; but, owing to the very nature of the fibrine, wherever it may be, within a short period after it is shut off from the circulation it exhibits this peculiar character, and coagulates inevitably.

Why, then, does it not coagulate in the vessels, and thus stop the circulation of the blood?

To understand this, we must remember that the history of all the animal substances in the living body is one of incessant change. None of them remain the same, but all undergo successive transformations. The albuminose formed in digestion is no sooner taken up by the blood-vessels than it is converted into albumen. The oily matters absorbed with the chyle, and the sugar produced in the liver, are also rapidly decomposed, as we have seen, and disappear in the circulation. What is destroyed in this way for the purposes of nutrition is constantly replaced by a fresh quantity formed in the same organs.

This is also true of the fibrine. That which is circulating in the blood-vessels to-day is not the same fibrine which was there yesterday, but a new supply, freshly produced in the process of daily nutrition. It is esti-

mated by physiologists that all the fibrine which exists in the blood is destroyed and reproduced at least three times over in the course of a single day. What the new substances are which are formed by its decomposition is still unknown, for we can not yet follow out all the details of these changes which take place so rapidly in the living body. But there is every reason to believe that the renovation of the fibrine in the blood takes place as constantly and rapidly as that of its other ingredients.

The blood, therefore, does not coagulate while the circulation is going on, because its fibrine is being incessantly altered and converted into new substances. It has been found that in certain of the internal organs, especially in the liver and kidneys, the fibrine disappears, and that little or none of it is contained in the blood returning from them. When we come to learn with what rapidity the circulation is carried on, we shall easily understand how coagulation may thus be prevented. But if the blood be withdrawn from the circulation altogether, or confined in any part by a ligature, then its fibrine can no longer go through with the natural changes of its decomposition, and it accordingly coagulates, as we have above described.

72. **Quantity of the Blood.** — The entire quantity of blood in the vessels is about one eighth part, by weight, of the whole body; so that in a man weighing 140 pounds, the quantity of blood is very nearly 18 pounds. The quantity of blood, however, as well as its composition, varies somewhat at different times. Soon after digestion it is considerably increased; for it has absorbed all the nutritious materials taken with the food, and these materials must necessarily pass through the

blood in order to reach the tissues. After long abstinence it is diminished in quantity to a corresponding degree. For the same reason, its composition varies to a certain extent, since its different ingredients will diminish or increase, according as they have been discharged or absorbed in greater or less abundance.

73. **Effects produced by Loss of Blood.**—Only a small proportion of the blood in the body can be lost without causing a serious effect upon the system. Generally speaking, the loss of one pound of blood causes faintness, and that of a pound and a half or two pounds is followed by complete unconsciousness. If the bleeding be then stopped, the patient usually recovers; but if a still larger quantity of blood be lost, recovery becomes impossible.

When the strength, however, has been very much reduced by excessive bleeding, it may sometimes be restored by injecting into the blood-vessels healthy blood from another person. This is called the "Transfusion of the Blood." In several instances where the vital powers were nearly exhausted, life has been restored by this operation.

74. **Two different kinds of Blood in the Body.**—Finally, there is a most remarkable difference in the appearance of the blood in different parts of the body. In one half of the circulation, that is, in all those vessels which are called "arteries," it is of a brilliant scarlet hue; while in the "veins" it is of a deep bluish-purple, almost black color. These two kinds of blood follow each other in the circulation, changing alternately from one color to the other; so that, although there is always red blood in the arteries, and always blue blood in the veins, yet the same blood is alternately scarlet and purple, as it

passes from one set of vessels into the other. This leads us, in the next place, to the subject of Respiration.

QUESTIONS FOR CHAPTER VII.

1. What fluid provides for the nourishment of the whole body?
2. What is the physical appearance of the blood?
3. What are its ingredients?
4. What is the use of the *water* of the blood?
5. What is the proportion of water in the blood?
6. What are the most important *mineral* ingredients of the blood?
7. What are the properties of the *albumen* of the blood, and how does it differ from the white of egg?
8. What is the proportion of albumen in the blood?
9. What is its use?
10. What is the distinguishing peculiarity of *fibrine?*
11. What is the appearance of the *blood globules?* their consistency?
12. Does the *color* of the blood reside in the liquid parts, or in the blood globules?
13. What change takes place in the blood when it is withdrawn from the vessels?
14. Which of the ingredients of the blood causes its coagulation?
15. Describe the separation of the blood into *clot* and *serum.*
16. What does the clot contain? What does the serum contain?
17. How does the coagulation of the blood control bleeding?
18. What should be done to check the bleeding from a wound of moderate size?
19. What must be done when a large artery is wounded?
20. Why does not the blood coagulate while circulating in the vessels?
21. How rapidly is the fibrine of the blood destroyed and reproduced?
22. In which of the internal organs does it disappear?
23. Why does it coagulate when shut off from the circulation?
24. What is the quantity of blood contained in the whole body?
25. What effect is produced by an excessive loss of blood?
26. What is the operation of "*transfusion?*"
27. What *two different kinds of blood are there in the body?*

CHAPTER VIII.

RESPIRATION.

The Oxygen of the Air—its Necessity to Life.—Nature of Respiration. —The Lungs—their Structure.—Larynx.—Trachea.—Bronchial Tubes.—Lobules.—Air Vesicles.—Movement of Inspiration.—The Diaphragm—its Contraction.—Entrance of the Air.—Intercostal Muscles.—Motion of the Ribs.—Movement of Expiration.—Elasticity of the Lungs.—Quantity of Air used in Respiration.—Movements of Respiration involuntary.—Effect of Respiration on the Blood.—Its Change of Color.—Venous Blood.—Arterial Blood. —Absorption of Oxygen in the Lungs.—Loss of Oxygen in the Tissues.—Carbonic Acid—where formed.—Discharged with the Breath.—Animal Vapor.—Watery Vapor.—Ventilation.—Ventilation by Doors and Windows—by Fires and Chimneys—by other Means.—Necessity for complete Ventilation.

75. **Oxygen.**—In the air which surrounds us, penetrating into the minutest crevices, and distributed every where over the surface of the globe, dissolved in the water, and diffused throughout the atmosphere, invisible but omnipresent, there is a substance of singular activity, and endowed with a most prominent part in the operations of nature. It forms and destroys odoriferous vapors, it corrodes the metals, it crumbles the texture of woody plants, it decomposes all dead and decaying materials, and it devours the substance of burning bodies. It is every where active, and every where ready to produce some new change in the materials of the inorganic world. This substance is *Oxygen*.

Oxygen is equally important in the organic world.

No animal can live without it; and it is incessantly in operation, uniting with the tissues, and forming a multitude of internal combinations which are necessary to existence. Furthermore, the activity of life in different kinds of animals is in exact proportion to the intensity with which they receive the influence of oxygen. The more sluggish of them, such as worms, shell-fish, and reptiles, require but little of it, and will still survive when deprived of it for a short time. But the more perfect the organization of the animal, and the more active its temperament, the more constant and imperative is its demand for oxygen. In the quadrupeds, in the birds, and in the human species, where the circulation is rapid and the movements vigorous, and where all the functions of life are in active operation, this substance is the first and most indispensable requisite to existence. With them oxygen is a food which must be incessantly supplied, for if it be withheld for only a few minutes together life inevitably comes to an end.

76. **The Atmosphere and Respiration.**—Now the great reservoir of oxygen, and the source from which it is constantly derived for our use, is the atmosphere.

Oxygen does not exist, however, in the atmosphere by itself. On the contrary, it is mingled there with another substance which is more abundant than it, but which does not possess its active properties. This substance is termed "Nitrogen." The quantities of the two are in such proportion that there is one part of oxygen to about four parts of nitrogen. The atmosphere, therefore, is a mixture of these two gases, in which the oxygen, which is active and powerful, is diluted with the nitrogen, which is mild and inert.

Consequently we depend directly upon the atmosphere for the maintenance of life. If it be withdrawn or shut out from us in any way, we die within a short time, because we are deprived of the oxygen which is essential to our existence.

The manner in which the air serves to support life is by penetrating into the interior of the body, into certain organs which are adapted for its reception. These organs are called the "Lungs." The air is drawn into them with the breath, and immediately after exhaled again, to give place to a fresh supply. This action, by which the air is introduced into the lungs, and there used for the maintenance of life, is the process of *Respiration.*

Let us see, first, how it is that the movements of respiration are accomplished; and, secondly, what are the changes thus produced in the interior of the body.

77. **The Organs of Respiration.**—The lungs are two large and exceedingly vascular organs, situated in the cavity of the chest, one on each side, and extending from about the level of the collar-bone to just below the region of the heart. They are "spongy" in their texture—that is, they are filled every where with little cavities, imperfectly separated from each other by slender partitions, like the tissue of a sponge. Each one of these cavities is filled with air; and so minute are they, and so closely packed together, that the whole substance of the lung is thus filled with small air-bubbles, disseminated every where through its tissue. If you take a piece of the lung, therefore, such as that of an ox or a sheep, and press it between the fingers, you will perceive a fine crackling sensation, owing to the partial dislodgment of these minute bubbles of air.

For the same reason, the tissue of the lung, unlike that of any of the other organs, will float in water. The substance of other organs, being solid and heavier than water, sinks at once to the bottom; but that of the lungs, every where infiltrated with air, is buoyed up by it, and floats lightly upon the surface.

These minute cavities, containing the air-bubbles just described, are called the "air vesicles" of the lungs.

Now the air which is thus disseminated through the lung has been derived from the external atmosphere. For the cavities of the lungs communicate with the exterior through certain channels or air passages, called respectively the *Larynx*, the *Trachea*, and the *Bronchial Tubes.*

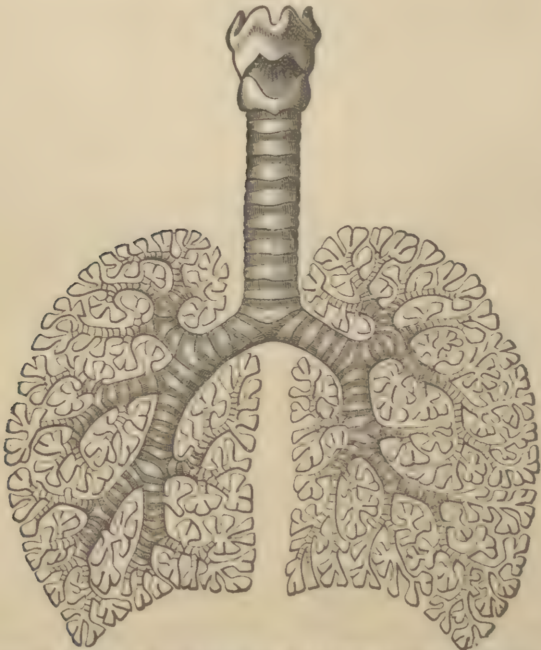
The larynx is a firm cartilaginous box or framework, situated directly at the front of the upper part of the neck, where it forms an angular prominence which is easily felt by the fingers. Internally the larynx is hollow, and communicates with the back part of the throat by a narrow chink or crevice, which is termed the "glottis." Through this chink the air passes from the nostrils and back part of the throat into the larynx.

From the larynx it passes downward into the trachea. This is a straight rounded tube, about an inch in diameter, which runs from the lower end of the larynx directly downward along the middle of the neck to the upper part of the chest. It is formed of membranous walls; but these are held apart, so as to secure a free passage for the air, by a series of elastic cartilaginous rings imbedded in their substance.

As the trachea enters the cavity of the chest it divides, right and left, into two tubes or "bronchi," one of which goes to each lung. Arrived at the lungs, the

bronchi themselves break up into smaller divisions, which are the "bronchial tubes;" and these tubes continue to separate into still smaller branches and ramifications. Each ramification of the bronchial tubes terminates at last in an oval sac or bag, separated in its interior into various divisions or compartments, into which the air penetrates from the end of the bronchial tube.

Fig. 32.



Human Larynx, Trachea, Bronchi, and Lungs; showing the ramification of the bronchi, and the division of the lungs into lobules.

These oval-shaped sacs are called the "lobules" of the lung, and, united together, make up its entire substance (Fig. 32).

Fig. 33.

Lobule of Human Lung.—*a.* Ultimate bronchial tube; *b.* Cavity of lobule; *c,c,c,c.* Air vesicles.

Finally, each lobule is itself composed of a group of small rounded cavities, called the "air vesicles," formed by the divisions or partitions which project from the inner surface of the lobule. Thus all the air vesicles contained in a lobule communicate with the central cavity of the lobule itself, and through it with the end of the bronchial tube (Fig. 33).

Now these divisions and ramifications of the interior of the lung produce a very large extent of surface, over which the air comes in contact with its tissue. Each air vesicle is only about $\frac{1}{75}$ of an inch in diameter; and we can easily understand, therefore, how many of them may be contained in an organ of the size of the lung. But each one of these air vesicles is in contact with the air over its whole internal surface, and all these surfaces combined must be very extensive. It is estimated by anatomists that the whole internal surface of the lungs, if spread out, would be many times greater than the whole external surface of the skin.

No doubt this is true. The page of an ordinary book, of the octavo form, represents about one third of a square foot. Such a book, one inch thick, will contain at least 400 pages, and will accordingly represent, altogether, a surface of 133 square feet. If you take out of the book every alternate leaf, so as to leave a layer of air of the same thickness between all the rest, there

will still be remaining, in contact with the air, a combined surface of 66½ square feet, which is very nearly four times the whole external surface of the human body.

The tissue of the lung, however, is much more delicate and complicated than the pages of a book, and is capable of much greater extension within the limits of the same space.

Thus the air passes from without through the larynx, trachea, and bronchi; and, following the successive divisions of the bronchial tubes, arrives at last in the cavities of the lobules and air vesicles. It thus penetrates throughout the tissue of the lung, and is disseminated over the immense extent of its internal surface.

78. **Movements of Respiration.**—But what is the mechanism of respiration, and how is the air constantly renewed in the interior of the chest?

It is by a double movement, by which the air is alternately drawn into the lungs and again expelled from them. These two acts are called the *movements of Inspiration* and the *movements of Expiration.*

First, the movements of Inspiration.

The lungs, as we have seen, are inclosed in the cavity of the chest, and communicate with the exterior only through the bronchial tubes and the trachea. Now the chest is separated from the abdomen by a strong muscular floor or partition, which is attached to the edges of the lower ribs in front and at the sides, and to the spinal column behind. This partition is the *Diaphragm.* It has an arched or vaulted form, so that its middle portion is higher than its edges, and projects upward like a dome into the chest. Above this arched portion, in the chest, are placed the lungs; beneath it, in the

abdomen, are the stomach and liver. When the diaphragm is at rest, these organs remain undisturbed in their position.

But the diaphragm is a muscle. Its fibres radiate every where from its central portion outward and downward, to be inserted into the firm edges of the ribs and the spinal column. When they contract, therefore, they draw the central part of the diaphragm downward, and the arched floor of the chest descends toward the abdomen. In its descent the diaphragm pushes before it the liver and the stomach; and at the same time the lungs follow its movement from above, and expand with the air which flows into them through the trachea. This is the movement of inspiration.

Accordingly, at the time of inspiration, we can feel that the abdomen protrudes, while the air passes in by the mouth and nostrils.

Now the air is drawn into the lungs at this time by the force of suction. It is not a violent action, however, but is accomplished by a gentle and easy movement, owing to the elasticity of the atmosphere, which enables it to penetrate every where where there is a space open to receive it. A little explanation will make this evident.

If you move a book from one end of a table to the other, it displaces the air from the spot in which it is deposited; but, on the other hand, the air at the same time occupies the space which the book has left. If you walk a few steps in any direction, the air, displaced by the movements of the body, fills at once the spot left vacant by the body itself. The air is so movable and elastic that, so long as sufficient space is allowed it, it takes indifferently either position.

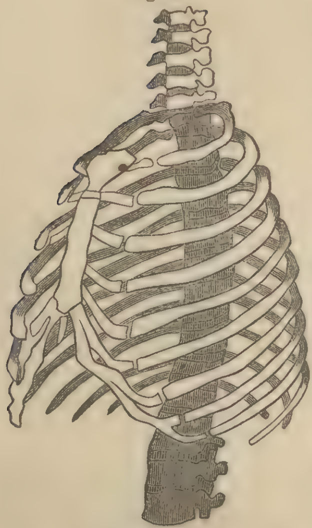
In the same way, if you take an empty syringe, holding it upright, with the nozzle pointing upward, and then draw down the handle of the piston, as the piston descends the air follows it from above, entering through the nozzle into the interior of the syringe, just as it passes into the lungs through the trachea during the descent of the diaphragm.

But, in order that this may happen, a space must be open for the air to move freely, both inside and outside the cavity which is to be filled; for if this space be not open to it, its resistance will be re-enforced by the pressure and elasticity of the entire atmosphere. When the lungs are full, close the mouth and nostrils firmly with one hand, and then try to compress the chest by the strength of the muscles. You can not; because the air within the chest has no exit, and resists, therefore, with the whole force of its elastic pressure. When the lungs are empty, on the other hand, close the mouth and nostrils as before, and endeavor to expand the chest. You can not; for the air outside the chest is unable to find an entrance, and resists with a pressure which is greater than the entire force of the muscles.

But when there is no obstacle to the free movement of the air, no resistance is offered by its pressure. The muscles have only to overcome the weight and elasticity of the organs set in motion, and the air then follows the movements of the diaphragm as gently and easily as a door swings upon its hinges.

The action of the diaphragm in inspiration is aided, at the same time, by the movements of the ribs. The ribs are of a curved form, and encircle the chest with a kind of bony cuirass or framework (Figure 34). They slant outward and downward, and overlap each

Fig. 34.



Part of the Spinal Column, with the ribs attached, inclosing the cavity of the chest.

other from above downward, somewhat like the shingles on the roof of a house; only the adjacent ribs do not touch each other, but are separated by a narrow space which is filled by so many intervening muscles. These muscles, being situated between the ribs, are called the "intercostal muscles." They contract at the same time with the diaphragm, and, by shortening their fibres, they lift the ribs and expand the cavity of the chest from side to side.

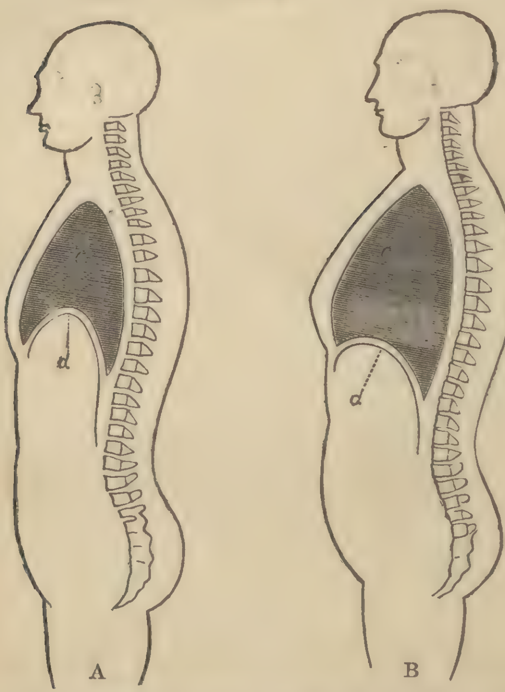
Thus during the act of respiration we can feel the chest rise and fall, as the air moves inward and outward through the passage of the lungs (Fig. 35).

The movement of Inspiration is immediately followed by the movement of Expiration.

As soon as the lungs are filled with air by the action of the intercostal muscles and the diaphragm, these muscles are relaxed, and the air is again expelled through the same channels by which it entered.

This is accomplished principally by the elastic reaction of the lungs. For throughout the tissue of these organs there are disseminated a great number of minute fibres, which have the property of elasticity in a high degree, and which therefore communicate this

Fig. 35.



A. Figure with the chest collapsed; B. Figure with the chest expanded; *c.* Cavity of the chest; *d.* Diaphragm.

property to the lungs themselves. The air vesicles and lobules are in this respect like so many little India-rubber bags; and after being filled with air they react upon it at the moment of expiration, and expel it by their own elasticity.

Beside this, the walls of the abdomen, pushed forward by the descent of the diaphragm, return to their places when this muscle is relaxed, and the liver and the stomach rise again to their former situations.

Thus the movement of inspiration is an *active* movement, produced by the contraction of the diaphragm and the intercostal muscles; that of expiration is a *passive* movement, caused by the elastic reaction of the lungs and the walls of the abdomen. These two movements follow each other alternately, with the successive contraction and relaxation of the respiratory muscles.

The movements of respiration are performed slowly but constantly. Under ordinary circumstances, a man breathes naturally about twenty times per minute. These motions are increased in frequency by any muscular exertion, but afterward return to their former regularity.

79. **Quantity of Air used in Respiration.**—At every respiration twenty cubic inches of air ($\frac{1}{3}$ of a pint) are taken into the lungs. If we count the entire number of respirations in a day, including those caused by muscular exertion, this will give about 600,000 cubic inches, or 350 cubic feet of air which passes and repasses through the lungs in every twenty-four hours. This is nearly eighty times the bulk of the whole body.

80. **Character of the Respiratory Movements.** — The movements of respiration are *involuntary.* The diaphragm descends and the chest expands without any exertion of the will, and even without our knowledge. From the instant of our birth to the last moment of existence, during the activity of our waking hours and in the unconsciousness of sleep, they continue in untiring and ceaseless operation. For the necessity of respiration is not occasional, but incessant; and the performance of this function, therefore, is not confided to the

will, but is provided for by an involuntary action, which requires no attention and produces no fatigue.

It is true that we can exercise a partial control over the movements of respiration; that is, we can hasten or retard them at will. But this is only for a very short time. If we try to breathe much more rapidly than is natural, say one hundred times a minute, we shall soon find how laborious and exhausting the movements become. On the other hand, if we stop respiration altogether, we at once feel an internal impulse which calls for its renewal, and which grows rapidly stronger and more imperative, until it becomes at last irresistible. There are few persons who can voluntarily suspend the breath for more than thirty or forty seconds at a time.

Such is the manner in which the movements of respiration are performed. Now let us see what happens while the air is thus taken into the cavity of the chest.

81. **Change in the Air during Respiration.**—In the first place, as the air penetrates into the lungs it is robbed of its oxygen. This substance disappears, so that the air which has once been drawn into the chest, and again expelled with the breath, no longer contains it in due proportion.

What has become of the oxygen which thus disappears from the air in respiration?

It is absorbed by the blood. For the blood-vessels coming to the lungs are distributed every where in the minute spaces between the air vesicles, and envelop their walls with an abundant vascular network. If we recollect the great extent of surface represented by the tissue of the lungs, we shall see that the blood circulating in their vessels is spread out over a corresponding

surface; and that, in a thousand minute currents, it moves through the lungs almost in contact with the air contained in the vesicles. It is as if the blood were sprinkled through the air in a fine shower; so that every particle of the blood and every particle of the air are brought into the closest proximity. At this moment the oxygen leaves the air and enters the blood over the whole internal surface of the pulmonary tissue.

82. **Change in the Blood during Respiration.**—At the same time a most remarkable change takes place in the blood itself.

The blood which is distributed to the lungs is venous blood. It is that which has already circulated through the organs and tissues of the body, and has served for their nutrition. From them it is collected by the veins, brought back to the heart, and from the heart distributed to the lungs. At this time it is of a dark blue or purple color, approaching to black.

Now, as this venous blood enters the lungs and takes possession of the oxygen contained in the air vesicles, it changes from a dark blue to a brilliant scarlet color. This change is instantaneous and complete; so that the blood, as it leaves the lungs on one side, is entirely different in appearance from that which is entering them on the other (Fig. 36).

After the blood has passed through the lungs and has changed its color from blue to red, it returns to the heart, and is again distributed throughout the body by another set of vessels, which are called the "arteries."

Accordingly, there are always two kinds of blood in the general circulation, of different colors and occupying two different sets of vessels. The blood in the veins is blue, and is called *Venous* blood; that in the arteries

Fig. 36.

Circulation through the Lungs.—*a*, *b*. Right side of heart, containing venous blood; *g*, *f*. Left side of heart, containing arterial blood; *c*. Blood-vessel conveying the blood to the lungs; *e*. Blood-vessel bringing it back from the lungs; *d*. Blood-vessels distributed in the lungs; *h*. Great artery going off from the heart.

is red, and is called *Arterial* blood. The blood is also constantly changed from venous to arterial while passing through the vessels of the lungs.

It is for this reason that the lips turn purple and the face assumes a dark ashen color whenever the breathing is seriously obstructed. For the blood, no longer becoming arterialized, retains its venous hue and communicates a dark color to all the transparent and vascular tissues.

But the change in color is not the only difference between these two kinds of blood. The venous blood, which has already circulated through the body, has lost its vital properties. It has expended a part of its substance in the nourishment of the tissues, and is no longer fit for the maintenance of life.

What is it that the blood has thus lost in passing through the tissues which is necessary to its vitality?

It is its oxygen.

For the arterial blood, as it passes out from the heart to be distributed throughout the body, carries with it the oxygen which it has absorbed in the lungs. It arrives at the tissues charged with this vivifying principle, and the tissues immediately seize upon it and appropriate it to themselves. Thus the blood, as it passes through the circulation, gives up its oxygen and returns to the venous condition. There is, therefore, a double change going on incessantly in the blood in the different parts of the body. In the tissues it loses oxygen, and changes from red to blue; in the lungs it absorbs oxygen, and changes from blue to red.

83. **Action of the Blood Globules in Respiration.**—Now the ingredients of the blood which are most active in producing this change are the *Blood globules.* It is these little bodies which take the oxygen from the air, and fix it in their own substance for the renovation of the blood. They are the carriers, which load themselves with oxygen in the lungs, to transport it afterward to distant parts in the current of the circulation. As all the color of the blood resides in them, we easily see why this color should change with the changing constitution of the globules themselves.

It is by the process of respiration, accordingly, that the blood is kept constantly renovated and restored to the arterial condition.

84. **Quantity of Oxygen Consumed.**—The importance of oxygen to the living body is shown by the quantity which is consumed. At every inspiration one cubic inch of oxygen is withdrawn from the air and absorbed

by the blood. This amounts in the course of an entire day to about 17½ cubic feet, or by weight a little over one pound.

85. **Evolution of Carbonic Acid.**—But, at the same time that oxygen is absorbed from the air in respiration, another substance makes its appearance in the lungs, and is expelled with the breath. This is *Carbonic acid.* It is a gas, like oxygen, but differing from it in its properties. It is the same gas which is formed in the fermentation of bread, wine, beer, and all substances containing sugar. It is produced from burning coal and candles, and many other combustible bodies. It is sometimes exhaled from the surface of marshy pools, and often collects at the bottom of old wells. It is not fit for respiration; and when a man is accidentally caught in an atmosphere composed of carbonic acid, as sometimes happens in cleaning beer-vats or in repairing old wells, he at once becomes insensible, and soon dies by suffocation.

This gas, as we have said, is found in the breath. No less than one twenty-fifth part of the air passing out of the lungs consists of carbonic acid. This is immediately diffused through the atmosphere, or carried away by its movements; and the fresh air then taken into the lungs is again loaded with carbonic acid and expelled in its turn. This process goes on with every successive respiration; so that in the course of an entire day the amount of this gas discharged with the breath is nearly 15½ cubic feet, or by weight about one pound and a half.

Now the carbonic acid so produced is formed in the tissues. It is absorbed from them by the blood, carried by the blood to the lungs, there exhaled into the pul-

monary vesicles, and finally discharged with the breath. It is a useless and exhausted material which the tissues have rejected, and which is therefore expelled from the body in the process of respiration.

86. **Exhalation of Water and Animal Vapors with the Breath.**—Beside carbonic acid, the breath also contains a peculiar animal vapor, which is produced in the interior of the body. Though this vapor is in very small quantity, it is sufficient to give to the breath a faint but perceptible odor. There is also some water discharged from the lungs in a gaseous form. The breath therefore is damp; and if we breathe upon a mirror, its polished surface becomes dimmed from the deposit of the watery parts of the expired air. In warm weather the moisture thus exhaled with the breath is imperceptible, because it is perfectly gaseous and transparent; but if the outer air be cold it is immediately condensed and becomes visible. Thus, on a winter's day, when the temperature of the air is low, the breath may be seen as a white cloudy vapor, issuing from the mouth and nostrils and diffusing itself in the atmosphere.

87. **Necessity for Fresh Air and Ventilation.**—From all that has been said, we see that the first and most indispensable requisite of health, and even of existence, is a constant supply of fresh air. Nature has provided for this, so far as the mechanism of the body is concerned, by the unceasing play of the movements of respiration, by which the air within the chest is renewed with every breath. If the air were not thus renewed, it would at once become altered and contaminated, and consequently incapable of supporting life.

The same thing, of course, would take place outside the chest. If we remain shut up in a close apartment,

breathing the same air over and over again, with every respiration it loses a part of its oxygen and becomes contaminated with carbonic acid. As we know how much oxygen is consumed with each respiration, we can easily calculate how long it will be before the whole of it in the atmosphere will be exhausted. At the same time the carbonic acid continues to accumulate, and thus the air confined in the apartment is constantly degenerating, until it becomes totally unfit to support respiration.

We must therefore renew the air in our houses and apartments, as carefully and thoroughly as it is renewed in the lungs by the movements of respiration.

The method by which this is accomplished is called *Ventilation.*

The ventilation of an apartment or of a house consists, like the respiratory movements, of a double process, viz., the introduction of fresh air from without, and the discharge of the contaminated air from within. It is effected by means of doors, windows, and chimneys.

In order that ventilation may be effectual, every apartment should have doors or windows upon two opposite sides, in order that the fresh air may pass completely through it, and thus remove every vestige of foul atmosphere. In the warm summer weather, and in ordinary apartments, this is nearly always sufficient, since both doors and windows are usually opened often enough to secure an abundant supply of air. But in winter, when the doors and windows are closed for a great part of the time to exclude the cold, other means are necessary. Ventilation is then aided by means of fires and chimneys.

Chimneys produce ventilation in this way. The air,

heated by the burning fuel in the fire-place, rises in the chimney, and the chimney itself becomes warmer than the rest of the building. A permanent current of heated air is thus established, which constantly rises through the chimney and is discharged from its upper extremity. This is the "draft" of the chimney. The hotter the fire, the more rapid and powerful is the draft, and the more complete the ventilation. For fresh air at the same time finds its way into the apartment through all the minute openings and crevices of the doors and windows. We can not seal up these openings sufficiently to exclude the air, so long as a heated current is constantly driven upward through the fire-place and the chimney.

A fire, burning in an open fire-place, is therefore the best and most effectual means of ventilation. Other methods of warming an apartment, such as close stoves, or iron pipes filled with hot water or steam, have no such good effect, for they produce no current. The atmosphere is warmed by them, but it does not move; and the air consequently remains in the apartment, imperfectly renewed and consequently vitiated by respiration. Such contrivances frequently economize fuel, but they economize it at the expense of something which is much more valuable, viz., the air and its oxygen, which are necessary to life.

But, beside this, in every inhabited dwelling-house, ventilation should be further secured by free opening of the doors and windows, and liberal admission of the external air at least once every day. For in every such house there are other sources of contamination for the atmosphere beside respiration. The preparation of the food by cooking, the cleansing of the apartments, and

the unavoidable daily accumulation of refuse of various kinds, produce emanations which are harmless when fresh, but which become offensive and injurious if allowed to remain and stagnate. We may be sure that *no atmosphere is wholesome where any of these stagnating odors are perceptible.* A house should therefore be swept throughout, each day, by a current of fresh air sufficient to maintain the cleanliness and salubrity of its atmosphere.

Still farther means are requisite in apartments where large numbers of persons are collected together; as in school-rooms, lecture-rooms, theatres, and manufactories. Here the contamination of the atmosphere is more rapid, being in proportion to the number of persons present. For the respiration of ten men will exhaust the atmosphere ten times as rapidly as that of one; and the quantity of air which would last a single person for five hours, in an audience of three hundred would be consumed in exactly one minute. The means of ventilation in these cases, accordingly, must be very much greater, in proportion to the size of the apartment, than in those used for ordinary habitation. Large openings are usually made in the walls or ceiling, leading into flues or passages which rise to the roof. These flues should be conducted alongside the chimneys, in the walls of the building; so that, being warmed by their contact, they may serve as so many additional chimneys to carry off the vitiated air of the apartment. In addition to this, a rotary fan, driven by machinery, is often employed to secure a constant supply of fresh air from without.

Whatever means of ventilation are employed, we may judge of their success by a very simple criterion.

After the apartment has been occupied for an hour, its atmosphere should be as pure as it was at first. Any ventilation which is less than this is insufficient; for every impurity which has collected in the air must necessarily be breathed by the occupants, and accordingly must vitiate their respiration to a corresponding degree.

The function of respiration, as we have seen, is a double process of absorption and discharge. It supplies incessantly to the body the oxygen which is necessary to life, and expels from it at the same time the carbonic acid produced in its tissues. It is by this process that the arterial blood is constantly renewed, and enabled to perform its natural office in the circulation.

QUESTIONS FOR CHAPTER VIII.

1. What natural substance is the most indispensable to life?
2. From what source is oxygen most abundantly obtained?
3. What other substance does the atmosphere contain beside oxygen?
4. Which of these two gases is most abundant in the atmosphere, oxygen or nitrogen?
5. Which of them is the active ingredient, and which is comparatively inert?
6. Why is it fatal to an animal to deprive it of atmospheric air?
7. What is the function of *respiration?*
8. What are the organs of respiration?
9. What is the structure of the lungs?
10. What is contained in the minute cavities of the lungs?
11. Through what passages is the air introduced into the lungs?
12. What is the *larynx*, and where is it situated?
13. What is the narrow opening called through which the air passes into the larynx?
14. What is the form and structure of the *trachea?*
15. What is the use of the cartilaginous rings of the trachea?
16. What are the *bronchi?* the *bronchial tubes?* the *lobules?* and the *air vesicles* of the lungs?

17. What is the object of the division and multiplication of the bronchial tubes and air vesicles?

18. What are the two movements by which the air is drawn into and expelled from the lungs?

19. What muscle forms the floor of the chest?

20. What is the form of the diaphragm?

21. When the diaphragm contracts, how is its form altered?

22. What effect does this have upon the lungs? what upon the organs of the abdomen?

23. By what force is the air drawn into the lungs when the diaphragm descends?

24. Is this a violent or a gentle action?

25. How do the *ribs* move at the time of inspiration?

26. What muscles serve to lift the ribs in inspiration?

27. What follows when the movement of inspiration comes to an end?

28. By what force is the air expelled from the cavity of the lungs?

29. Which of the movements of respiration is an *active*, and which a *passive* movement?

30. How many respirations are usually performed per minute?

31. By what are the movements of respiration accelerated?

32. How much air is introduced and expelled at each respiration?

33. What is the average quantity of air used in twenty-four hours?

34. Are the movements of respiration voluntary or involuntary?

35. What substance disappears from the air in respiration?

36. What becomes of the oxygen which disappears in the lungs?

37. What effect does this have upon the color of the blood?

38. What is *venous* blood? and what is *arterial* blood?

39. Why do the lips turn purple when respiration is obstructed?

40. What change takes place in the blood while circulating through the tissues? what is the function of the *blood globules?*

41. How much oxygen is consumed by respiration in twenty-four hours?

42. What substance is *exhaled* from the lungs in respiration?

43. From what other sources is carbonic acid produced?

44. Is carbonic acid capable of sustaining life?

45. What proportion of carbonic acid is contained in the breath at each expiration?

46. How much is discharged from the body in twenty-four hours?

47. Where does the carbonic acid come from which is exhaled with the breath?

48. What other substances are exhaled with the breath beside carbonic acid?

49. What gives the breath its *odor?*

50. What makes it *cloudy* upon a cold day?

51. What effect is produced upon the air by continued respiration in a confined space?

52. What is *ventilation?*

53. What is the most effectual means of ventilation?

54. Why are close stoves, hot water, or steam-pipes bad means for warming an apartment?

55. Why should a house be also ventilated every day by opening the doors and windows?

56. Why should the means of ventilation be increased in school-rooms, lecture-rooms, etc.?

57. What is the necessary rule or criterion for sufficient ventilation?

CHAPTER IX.

THE CIRCULATION.

The Organs of Circulation.—The Heart—its Muscular Fibres.—Auricles.—Ventricles.—Pulmonary Artery.—Aorta.—Movement of the Blood through the Heart.—Contraction of the Heart—its Relaxation.—Valves of the Heart.—Ventricular Valves.—Semilunar Valves.—Action of the Heart involuntary.—The Arteries.—Arch of the Aorta.—Distribution of the Arteries—their Elasticity.—The Pulse—how felt.—Rapidity of the Pulse.—Pressure on the Blood in the Arteries.—The Capillaries.—Capillary Network.—Circulation of the Blood in the Capillaries.—The Veins—their Valves.—Movement of the Blood in the Veins.—Obstruction of the Circulation by compressing the Veins.—Rapidity of the Circulation.—Its local Variations.

88. **Circulation of the Blood.**—The blood, enriched by the products of digestion, and arterialized by the influence of the air, is the medium through which the nourishment of the whole body is accomplished. It is destined to visit every part of the system, and to supply the necessary materials of life, which it carries with it in the current of the circulation. By the circulation, accordingly, we mean that continuous round or circuit of the blood by which it passes from the heart outward for the nutrition of the tissues, and from the tissues back again to the heart, to be renewed by respiration in the lungs.

The organs of the circulation are, first, the *Heart*, and, secondly, the *Blood-vessels*. The blood-vessels are the tubes which convey the blood in its movement

throughout the body; the heart is the organ which impels it onward in its course.

89. **The Heart.**—The heart is a muscle. Like the stomach, it is a hollow organ with two openings, one of entrance and one of exit, and provided with muscular walls, so that its contractions force every thing which enters it at one extremity to pass outward by the other. Only, in the heart these muscular layers are exceedingly abundant and powerful, and its contractions accordingly are rapid and energetic. While, therefore, the food during digestion passes but slowly and gradually through the stomach, the blood is propelled by the contractions of the heart in a forcible and impetuous stream.

The heart is situated in the middle of the chest, between the two lungs, and almost directly behind the breast-bone. It is a little larger than the clenched fist. It is somewhat conical in form, being wide at its upper part, and narrower and rather pointed below. The upper and wider portion of the heart is placed exactly in the middle of the chest, but its lower part is turned obliquely to the left. If we place the fingers in the space between the fifth and sixth ribs, a little to the left of the breast-bone, we can feel the point of the heart at each muscular contraction striking the side of the chest from within.

The heart consists of four different cavities, two on each side, called respectively the *Auricles* and the *Ventricles.* In each case the "auricle" receives the blood coming into the heart by the veins, and the "ventricle" drives it out by the other extremity into the arteries. As this is done at the same time on both sides of the organ, right and left, there are accordingly, first, a

"right auricle" and a "left auricle;" and, secondly, a "right ventricle" and a "left ventricle." We shall begin by describing the auricle and ventricle of the right side.

The right auricle is the receptacle of all the venous blood returning from the body. This blood is collected from the different veins into two great venous trunks, which meet on the right side of the heart and open into the cavity of the auricle. The auricle itself is a kind of muscular bag which receives the blood through this opening of the veins, and then urges it onward through another rounded opening, situated near by. This second orifice leads into the ventricle; and because it forms the entrance into this cavity, it is known by the name of the "ventricular orifice."

The ventricle is much larger than the auricle, and its muscular walls are thicker and stronger. As it contracts, it sends the blood through an opening at its farther extremity into a large artery, which is called the "pulmonary artery." This artery leads to the lungs. As it reaches the lungs it divides into numberless branches and ramifications, which penetrate, as we have said, into all the minute spaces between and around the air vesicles. It is while passing through these channels that the blood is arterialized by the influence of the air. The bright red arterial blood is then collected from the lungs and returned to the heart by corresponding veins, called the "pulmonary veins," which open into the left auricle.

The left auricle is similar in its structure to the right auricle. It opens by a corresponding orifice into the left ventricle.

The left ventricle is by far the thickest and strongest

portion of the heart. Its muscular walls are three quarters of an inch in thickness; and they require this additional force, for they are intended to propel the blood, by their muscular contractions, all over the body. The left ventricle opens by its farther extremity into the commencement of a large and strong artery, which receives all the blood coming from its cavity. This artery is termed the *Aorta.* From the heart it rises upward for a short distance, and then, curving over in an arched form, it passes downward through the chest and abdomen, sending off, right and left, all the branches which distribute its blood to the different regions of the body.

In Fig. 37 the two sides of the heart are shown, together with the course of the blood, from the right cavities through the pulmonary artery to the lungs, thence by the pulmonary vein to the left auricle, and finally from the left ventricle through the arch of the aorta into the commencement of the arterial system.

In studying this part of the circulation, two things especially claim our attention. First, the movements of the heart; and, secondly, the action of its valves.

90. **Movements of the Heart.**—In the movements of the heart the two auricles first contract together, and then the two ventricles follow, also simultaneously with each other. The contraction of the ventricles is much more powerful than that of the auricles, owing to the greater thickness of their walls. The two sides of the heart therefore move exactly together, the contraction beginning with the auricles and finishing with the ventricles. The whole, taken together, forms one entire act or movement of the heart, which is called its "pulsation." It is this movement which can be felt, as we

Fig. 37.

Circulation through the Heart and Lungs.—1. Right Auricle; 2. Right Ventricle; 3. Pulmonary Artery and its Branches; 4. Pulmonary Veins; 5. Left Auricle; 6. Left Ventricle; 7. Arch of the Aorta; 8. Branches of the Aorta.

have said, immediately below the fifth rib on the left side of the chest.

The contraction of the heart is immediately followed by its relaxation. In this respect it is like all other muscles, which require that intervals of repose should alternate with their periods of activity. But in the heart these alternating contractions and relaxations follow each other with a continuous and almost uniform rapidity.

PHYSIOLOGY.

JANUARY, 1876.

1. By what two means is the body held erect? Describe the manner in which the hand and arm are raised. Describe one means by which the body is protected from sudden jars.

2. Show the importance of lime as an ingredient of food. Which of the necessary ingredients is acted upon by the gastric juice? Name two conditions requisite for healthy digestion.

3. Describe the lining membrane of the stomach. Trace the course of the food through the digestive organs, and state briefly the change it undergoes in each.

4. Describe the Thoracic Duct. When are the lymphatics called lacteals and why? What two substances are produced in the liver and what becomes of them?

5. When will the blood coagulate in the interior of the body? Name the organs of respiration and describe two of them.

6. The difference between arterial and venous blood. The office of the blood globules.

7. Describe the arrangement and distribution of the arteries; the manner in which the blood is moved through the arteries.

8. What is the source of animal heat? How do the tissues of the body obtain materials for their nourishment? Name the two kinds of nerve fibres and describe the office of each.

9. What is the effect of an injury to the spinal chord? Describe the reflex action of the spinal chord and show why it is important? What is the office of the retina?

10. Describe the manner in which sounds are transmitted from the tympanum to the auditory nerve. Name two conditions requisite for the sense of taste; one use of this sense.

91. **Action of the Valves.**—But how is it that these movements cause the blood to flow onward in its natural direction? Why do they not expel it from the heart altogether, or drive it backward into the veins? This brings us to the consideration of the *Valves.*

A valve is simply a movable partition or obstacle, which swings open in one direction and closes in the other. A door is a valve. You can open it freely from without inward; but when you shut it, it closes firmly against the framework of the doorway, and can not pass beyond. The same office is performed by the valves of a pump, or those of a steam-engine. They are made of different materials, but they all act in a similar way. Before one of them was ever constructed, there were valves in the interior of the heart.

At the edges of the narrow opening between the auricles and ventricles, on each side of the heart, there are placed broad sheets of a thin but strong fibrous membrane, which are called the "ventricular valves." These valves hang loosely into the cavity of the ventricle, and are easily pushed aside by the current of blood entering from the auricle (Fig. 38). They do not, therefore, offer any obstacle to the movement of the blood in this direction.

But when the ventricle contracts, in order to expel the blood from its cavity, the valves are lifted by the impulse of the blood, their edges come together, and they close completely the ventricular orifice. They would then be forced backward through this orifice into the auricle, but for a number of strong fibrous cords which sustain them in their places. These cords are attached to the edges and under surface of the valves, and, passing downward, are attached to little

Fig. 38.

Right Auricle and Ventricle.—Ventricular valves open; Semilunar valves closed.

muscular eminences, or columns, on the sides of the ventricle. These muscular columns contract at the same time with the walls of the ventricle, and by the aid of their tendinous cords hold the valves in position, and prevent the regurgitation of the blood (Fig. 39).

The blood, therefore, which can not return into the auricle, is forced to find exit in the opposite direction, and escapes into the orifice of the corresponding artery.

There are also valves at the entrance of the great arteries. They are in the form of semicircular bags or festoons, and are therefore called the "semilunar" valves. They open into the artery to admit the current of blood (Fig. 39), and again shut back to close its orifice when the ventricle is relaxed (Fig. 38).

Thus these valves move backward and forward, and

Fig. 30.

Right Auricle and Ventricle.—Ventricular valves closed; Semilunar valves open.

alternately open and shut with each pulsation of the heart. The blood, accordingly, can never go backward, but is carried in a continuous circuit from the right side of the heart to the left, through the successive channels of the circulation.

92. **Character of the Heart's Action.**—Lastly, the movement of the heart is *involuntary.* It is still more independent of our control than the movements of respiration; and we can not hasten or retard it in the least degree, much less arrest it for even a single pulsation. It is kept up by the operation of an internal stimulus, which is entirely withdrawn from the influence of the will.

Nevertheless, it is affected by many involuntary emotions. Joy or sorrow, anger or excitement, will disturb

the regularity of its motions, and increase or diminish their rapidity. Disagreeable sights or sounds, and various moral emotions, will sometimes affect its action to such an extent as to produce faintness; but after the disturbing cause has passed away, the heart recovers its force and resumes the natural regularity of its movements.

We now pass from the study of the heart to that of the blood-vessels.

93. **Arrangement and Distribution of the Arteries.**—The first set of vessels into which the blood passes on leaving the heart are the *Arteries*. The arteries begin, as we have already said, with the aorta. This vessel rises from the left ventricle for a short distance behind the breast-bone, and then curves downward, forming a semicircular bend near the top of the chest, which is called the "arch of the aorta." From the arch of the aorta there are given off several large branches (Fig. 37 [8]), which supply the blood for the two arms and the two sides of the head. The aorta then passes downward parallel with the spinal column, through the chest and abdomen, giving off every where branches to the various internal organs. In the lower part of the abdomen it finally separates into two equal divisions, one of which supplies the right lower extremity, the other the left. Thus all the different parts of the body are provided with branches coming from the aorta.

When the arterial branches arrive at the organs to which they belong, they break up into innumerable subdivisions. These divisions grow smaller and smaller at the same time that they become more numerous; until the whole substance of the organ is penetrated by their ramifications, and every part of it is provided with a due supply of arterial blood.

The arterial system is therefore like a great tree, of which the aorta is the trunk, and the smaller arterial branches are the twigs and ramifications; only this arterial tree is every where hollow, forming a connected series of vascular canals.

94. **Elasticity of the Arteries.**—Now the arteries are *elastic.* If we take a piece of the aorta of an ox or a sheep, we shall find that we can stretch it, and that afterward it will retract and recover itself like so much India-rubber. The same property belongs to the arteries of the human body in a nearly equal degree. This quality is due to the presence of elastic fibres in the walls of the arteries similar to those which we have already spoken of in the lungs; only in the arteries these fibres are much more abundant than in the lungs, and their elastic reaction is therefore more rapid and powerful.

The elasticity of the arteries has a most important share in the circulation of the blood.

95. **Pulsation of the Arteries.**—At each movement of the heart, the left ventricle throws the blood into the aorta with the whole power of its muscular contraction. This distends the aorta and its branches, with an impulse which is felt throughout the arterial system. The heart is like a force-pump, driving the blood into the elastic arterial tubes; and the arteries open to receive it, because the strength of the heart is greater than their resistance. This expansion of the arteries, produced at each stroke of the heart, is called the *Pulse.*

The pulse may be felt wherever an artery can be examined. If we press the fingers firmly upon the upper and front part of the neck, just alongside the situation of the larynx, we shall feel the pulsation of the great

arteries which supply the head, and which are called the "carotid" arteries. It is still better when the artery crosses a bone near the under surface of the skin. Immediately in front of the middle of the ear is a small artery passing upward to the temples and the outside of the head, called the "temporal" artery, which we can easily feel by pressing lightly upon the skin in this situation. Just above the wrist, in front of the outer bone of the arm, is another artery supplying the hand and fingers, called the "radial" artery. This is the artery which the physician selects for feeling the pulse, simply because its situation is a convenient one for that purpose.

For the pulse is a valuable guide in learning the condition of the heart. As each stroke of the pulse represents a contraction of the heart, by counting the one we know the rapidity of the other. In grown-up persons, during health, the pulse beats about seventy-five times per minute. In fevers and inflammations, when the irritability of the heart is excited, it rises to eighty, ninety, one hundred, or even more than this. Many other peculiarities of the pulse, such as its strength, its fullness, its regularity or irregularity, show corresponding variations in the action of the heart, and indicate the condition of the circulatory system.

96. **Movement of the Blood through the Arteries.**—But at the moment when the heart is relaxed, the arteries still exert their elastic force. The blood is prevented from returning into the ventricle by the closure of the semilunar valves, and is thus forced onward through the arterial system.

The blood in the arteries is therefore under an inces-

sant pressure. It is always compressed by the elastic reaction of the arterial walls, and at each stroke of the heart it is urged by an additional pressure, derived from the muscular contraction. It thus moves through the arteries in successive waves or impulses, passing rapidly from the heart toward the ramifications of the arterial system.

97. **The Capillary Blood-vessels.**—The arteries terminate in another set of blood-vessels, still finer and more minutely subdivided, which are termed the *Capillaries.*

The capillaries are invisible to the naked eye. They are so small that they require the aid of the microscope for their examination, and yet they are the most important part of the whole circulating system, for it is in them that the blood comes into intimate contact with the substance of the tissues.

These vessels are formed of an exceedingly thin and delicate membrane. They penetrate every where among the cells and fibres of the different organs, and form so many minute channels by which the blood makes its way through the tissues. Their great peculiarity is that they constantly unite and communicate with each other in every direction like the meshes of a net, so that they form what is called the "capillary network" (Figure 40). The meshes of this network have different forms in different organs, but they every where present the essential characters above described.

Fig. 40.

Capillary Network in the web of the Frog's foot, magnified.

In some cases the circulation of the blood in the capillaries can be seen. In the transparent web of the frog's foot, when placed under the microscope, the blood globules can be perceived shooting along through the smaller arteries and penetrating into the capillary network (Fig. 41).. Here the currents often turn and wind in various directions, passing through the various communications between the different capillary vessels, and penetrating in this way, in a multitude of different streams, the various tissues of the part. As the red globules in the frog are larger than those of human blood, and of an oval form, they are readily seen while carried along with the current of the blood.

Fig. 41.

Capillary Circulation in the web of the Frog's foot.

The movement of the blood in the capillaries is steady and incessant. There is no pulsation here similar to what takes place in the arteries. For, by the successive division and multiplication of the smaller vessels and the combined influence of their elastic walls, the arterial pulsation has been equalized and converted into a continuous pressure; and under this pressure the blood moves through the capillaries in a uniform and uninterrupted stream. It is in this part of the circulation that the blood loses its oxygen, and becomes changed from the arterial to the venous condition.

98. **The Veins and the Venous Circulation.**—From the capillaries the blood is collected into larger channels, and so returned to the heart by means of the *Veins.*

We have already studied the structure of the veins in different organs. We know how they are formed by the union of the smaller branches into larger and larger trunks. The arrangement of the veins, therefore, is exactly the opposite to that of the arteries. The arteries divide and separate as they pass from the heart outward; the veins unite and coalesce as they pass from the capillaries inward. In this way the continuous circuit of the blood is effected from the arteries to the veins, through the capillaries, which are the channels of communication between them; so that the same blood which passes from the left side of the heart into the arteries, is returned at last to the right side of the heart by the veins.

We can easily convince ourselves that the blood moves in the veins from without inward. If we clasp tightly the lower part of the arm, a little above the wrist, we shall soon see the veins on the back of the hand enlarge and become turgid, until we can almost see the blue color of their blood through the semi-transparent skin. This is because the blood accumulating from behind can no longer find its way back to the heart, and consequently distends the veins below the situation of the pressure; but as soon as the pressure is taken off, the veins empty themselves toward the heart, and again disappear beneath the skin.

Now as many of the veins are situated very near the surface, they are often liable to be partially compressed and obstructed, as above, by the pressure of the clothing and the accidental contact of foreign bodies. But this does not stop the circulation of the blood; because, in the first place, the veins communicate with each other by frequent lateral branches, and, secondly, they

are provided at many points with valves, resembling the semilunar valves of the heart, which prevent the blood from being forced backward into the capillaries. When the circulation is obstructed, therefore, in a single vein, the blood passes off by a lateral channel, and thus still finds its way back to the heart. In order to check the venous current effectually, it is necessary to encircle the whole limb with a simultaneous pressure, as in the experiment on the veins of the arm above described.

But we should take the greatest care that no such pressure is left upon any part of the body as to interfere in this way with the venous circulation; for a ligature which compresses an entire limb, however lightly, is liable to obstruct the movement of blood in the veins, and thus interfere with the entire circulation in that region. This injurious effect is indicated by the swelling of the parts below the ligature; and if continued habitually, it will at last cause a permanent injury to the limb by preventing the due nutrition of its tissues. In young children, where the process of growth and development is constantly going on, these bad effects are especially injurious. No such pressure, therefore, should be left upon any part of the body as will interfere with the venous circulation; but the blood should be left every where free to find its way back to the heart through the natural passages of the vascular system.

Two other important points remain to be noticed in the phenomena of the circulation.

99. **Rapidity of the Circulation.**—In the first place, the circulation of the blood is *exceedingly rapid.* This rapidity is so great that it would be incredible, were it not for abundant experiments which have established it

beyond a doubt. The time required for the blood to circulate over the body and return again to the heart is not more than from twenty-five to thirty seconds. During this period it passes through the arteries, traverses the capillary network, returns by the veins, and is again transported through the lungs to the left side of the heart. We can understand, therefore, how rapidly the changes in the tissues may go on, and how soon an impurity in the blood, from deficient respiration or otherwise, will be felt in the remotest parts of the circulation.

100. **Variations of the Circulation.**—Secondly, the circulation exhibits, from time to time, *local variations* of an important character. Sometimes these variations are occasional and irregular, as where the face becomes flushed from mental emotion, or where any part of the skin is reddened by some accidental irritation, like a blister or a burn. But most of them are regular and periodical. Thus the stomach and intestine are flushed and congested during the digestion of the food, and this excitement passes off when digestion is finished. The salivary glands become reddened with blood while the secretion of saliva is going on, and afterward return to their ordinary pallid condition. Nearly all the internal organs have their periods of rest and their periods of activity; and their periods of activity are accompanied by a local excitement of the vessels, by which they are supplied at that time with an increased amount of blood. These temporary variations in the circulation of the blood are under the involuntary control of the nervous system, by which the necessary stimulus is conveyed to the different organs.

QUESTIONS FOR CHAPTER IX.

1. What is the *circulation of the blood?*

2. What are the *organs* of the circulation?

3. Of what is the tissue of the heart composed?

4. What is the situation of the heart? its size? its form?

5. Where can the point of the heart be felt?

6. How many cavities are there in the heart? their names?

7. Whence does the right auricle receive its blood?

8. Whither does the blood go from the right auricle?

9. How does the right ventricle differ from the auricle?

10. Into what vessel does the blood go from the right ventricle?

11. Whither is the blood conveyed by the pulmonary artery?

12. What vessels bring the blood back from the lungs? and into what cavity do they empty?

13. Whither does the blood pass from the left auricle?

14. Why is the left ventricle stronger than the other portions of the heart?

15. Into what vessel does the blood pass after leaving the left ventricle? and whither does this vessel carry it?

16. Which of the cavities of the heart contract simultaneously with each other?

17. What is the movement of the heart in contraction called?

18. What follows after each contraction of the heart?

19. What is a *valve?*

20. What is the situation of the *ventricular valves?*

21. What is their structure?

22. Which way do they open, and which way do they shut?

23. What prevents the valves from being forced back into the auricle at the time of the heart's pulsation?

24. What is the situation of the *semilunar valves?* their form?

25. Which way do they open, and which way do they shut?

26. What effect do the valves have upon the movement of the blood?

27. Is the action of the heart voluntary or involuntary?

28. How may it be accelerated or retarded?

29. What are the first set of blood-vessels which convey the blood outward from the heart?

30. Describe the aorta and its branches.

31. What becomes of the arteries when they arrive at the different organs?

32. What is the principal physical peculiarity of the arteries?

33. What is the *arterial pulse?*

34. In what situations may the arterial pulse be felt?

35. What is the average rapidity of the pulse in health?

36. By what may it be accelerated or disturbed?

37. At the relaxation of the heart, what effect is produced on the blood by the elastic pressure of the arteries?

38. How does the blood move through the arterial system, steadily or in waves?

39. What is the next set of blood-vessels in which the arteries terminate?

40. What is the size and structure of the capillary vessels?

41. What is the *capillary network?*

42. How can the circulation of the blood in the capillaries be seen?

43. How does the movement of blood in the capillaries differ from that in the arteries?

44. Into what vessels does the blood pass after leaving the capillaries?

45. What is the general arrangement of the veins, and what is the course of the blood through them?

46. What is the effect of *compressing* the veins by bandages or otherwise?

47. What permanent injury may be produced by obstructing the venous circulation?

48. How long a time is required for the blood to pass throughout the whole body?

49. What are the *local variations* of the circulation in particular parts?

CHAPTER X.

ANIMAL HEAT.

Warmth of Living Bodies—how preserved.—Production of Animal Heat.—Warm-blooded Animals.—Cold-blooded Animals.—Temperature of the Human Body.—Source of Animal Heat.—Difference in Temperature of the Internal Organs.—Animal Heat necessary to Life.—Effects of cooling the Blood and Internal Organs.—Regulation of Heat by Perspiration.—Perspiratory Glands.—Composition of the Perspiration.—Insensible Transpiration.—Increase of Perspiration by Heat.—Effect of its Evaporation.—Effect of heating the Blood above 100° Fahrenheit.—Solid Ingredients of the Perspiration.—Sebaceous Secretion.—Necessity for frequent Bathing.

101. **Animal Heat.**—One of the most remarkable qualities of animal bodies is their heat. Place your hand upon any part of the skin, and you feel that it is warm to the touch; that is, it is warmer than the atmosphere, or than surrounding bodies at ordinary temperatures. Animals, when exposed to cold, crowd together to protect themselves from its influence, and endeavor to preserve their warmth by mutual contact. Even the breath which is expelled from the lungs in respiration is warmer than the fresh air which entered a moment before. So general and characteristic is this quality in living animals that we instinctively regard their warmth as an indication of vitality, and its absence as a sign of death.

Furthermore, if we measure the warmth of the living body by the thermometer, we shall find that it is al-

ways very nearly the same. Take the bulb of the thermometer between the fingers of the closed hand, and it already rises to 90 or 95 degrees. But place it in the interior of the mouth, beneath the tongue, and keep it there for a few moments protected from the air, and it will stand at 100 degrees of Fahrenheit. This, accordingly, is the temperature of the internal parts.

Now this internal temperature is nearly invariable. In winter and in summer, in the arctic regions as well as in the torrid zone, even though the external parts be chilled or frostbitten, the internal temperature of the body is still 100 degrees of Fahrenheit, or thereabout. But as the temperature of the air is nearly always far below this point, the living body must be constantly losing heat by contact with the cooler atmosphere. How, then, does it keep up its own temperature at this elevated standard, notwithstanding a continual loss of heat from the external surface?

102. **Internal Production of Heat.**—There is only one way in which this is possible. The living body produces or generates heat in its interior, and thus constantly replaces what is lost from without. The internal heat, so produced, is known by the name of *Vital* or *Animal heat.*

All animals produce heat with more or less rapidity. In birds and quadrupeds, as well as in the human species, this production is so active that their blood and internal organs are nearly always considerably above the external temperature; they are therefore called "warm-blooded" animals. In reptiles and fish, on the contrary, the production of heat, like most of the other internal functions, is sluggish and feeble, and their temperature varies but little from that of the air or

water in which they live. Their temperature is so much below our own that we call them "cold-blooded" animals.

Accordingly, it is by its own internal heat that the living body is warmed. When we cover ourselves with clothing for protection from the cold, it is not that this clothing has any warmth in itself; it simply prevents the internal heat of the body from being dissipated. Even when we warm our houses with furnaces and fires, we only prevent, in a similar way, the body from being too rapidly cooled. For the atmosphere, even in the warmest apartment, never rises to the heat of the living body, which is still the only source of its own vital temperature.

103. **Animal Heat necessary to Life.**—This elevated temperature of the animal body is essential to life. The external parts of the frame, especially those which are thinner and more exposed, such as the ears and the fingers, may be chilled by the external cold, and again recover themselves; but if the internal organs and the blood be cooled down a few degrees below their natural standard, death inevitably results. The muscular power is diminished, the sensations become dull, the circulation of the blood is enfeebled; and the torpidity of the system gradually increases, until life is finally extinguished.

104. **Source of Animal Heat.**—The source of the animal heat is in the nutritive changes going on within the body. We know that heat may be produced in a variety of different ways—by the rays of the sun, the friction of solid substances, the compression of air, the passage of electric currents, and the burning of combustible bodies. It is also produced by many different

chemical changes, by solutions, combinations, and decompositions of various kinds. Every one knows how much heat is evolved by the combination of lime with water; and a mixture of water with sulphuric acid will produce a similar effect. Now, in the interior of the animal frame, an innumerable variety of these chemical changes are constantly going on. They are not all similar to those which take place outside the body, and the details of many of them are still unknown to us; but they are in incessant operation, and are sufficient to produce, for their final result, the elevated temperature of the living body.

105. **Variations and Equalization of Animal Heat in different Organs.**—Accordingly, the temperature of the different internal organs is not exactly the same, since the chemical changes which go on in their tissues are different. Careful experiments have shown that this difference in temperature sometimes amounts to nearly 1½ degree of Fahrenheit. Thus far the liver has been found to be the warmest of all the internal organs; but the blood, which also, no doubt, generates heat of its own, passes so rapidly through the circulation that it distributes the warmth of the internal organs, and thus tends to equalize the temperature of the whole. The external surface, therefore, which is in contact with the atmosphere, is kept constantly warmed by the blood coming from within; and the different parts of the body, when carefully examined, show but little variation from the standard temperature.

106. **Regulation of Animal Heat by Perspiration.**—But it is also remarkable that the temperature of the body is not only thus kept up to a natural standard, but that it never rises above this standard in any appre-

ciable degree. If the same amount of heat were generated in summer as in winter, we should expect the body to become warmer; since less heat is lost by contact with the atmosphere. But no such variation occurs. As in winter the internal temperature of the body never falls below 100 degrees, so in summer it never rises above that point. How is it that the warmth of the body is thus regulated?

It is by means of the *Perspiration.*

Immediately beneath the skin, over the whole surface of the body, but more abundantly on the palms of the hands, the soles of the feet, and the front parts generally, there are a multitude of little glandular bodies which are called the "Perspiratory glands." Each one consists of a slender tube, about $\frac{1}{400}$ of an inch in diameter, which penetrates from the surface through the whole thickness of the skin, and there terminates in a globular coil, very much like a mass of small intestines in miniature. The capillary blood-vessels distributed to these glands are interwoven with their coils, and cover their surface with a fine vascular network.

Now, although these glands are so small, yet they are also so numerous that, when taken together, they form an important glandular system. Each one of them, when its coil is carefully unraveled, is about $\frac{1}{15}$ of an inch in length. According to the best calculations, the whole number of perspiratory glands in the body is about 2,300,000. The combined length of their glandular tubing is therefore not less than 153,000 inches, or about two miles and a half.

Throughout this extent of the glandular tubes the blood of the capillary vessels comes in contact with their tissue. It there supplies a watery fluid, which is

poured into their cavities and finally discharged upon the surface of the skin. This fluid is the perspiration.

If the perspiration be examined by chemical analysis, it is found to have the following composition:

COMPOSITION OF THE PERSPIRATION.

Water	995.00
Animal matters, with lime	.10
Sulphates, and substances soluble in water	1.05
Chlorides of sodium and potassium, and spirit-extract	2.40
Acetic acid, acetates, lactates, and alcohol-extract	1.45
	1000.00

We see, therefore, that the perspiration is composed principally of water. The animal matters which it contains produce in it a faint and peculiar odor, and its acetic acid gives it a slightly acid reaction; but more than ninety-nine one hundredths of its materials consist of water.

Now the perspiration is secreted all the time. The minute blood-vessels pour out its ingredients into the slender cavities of the glandular tubes; and, as these become filled, they discharge their contents through their external openings upon the skin, so that the skin is constantly exuding a watery fluid upon its surface. Nevertheless, we do not see this fluid; indeed, it does not remain, usually, for one instant upon the skin, but is at once taken up by the atmosphere and dissipated by evaporation. This is what is called the "insensible transpiration" of the skin.

The surface of the body, therefore, though constantly supplied with moisture from its glands, is constantly dry, because all the moisture is at once carried off by evaporation. The effect of this evaporation is to cool the surface.

Evaporation is one of the most effectual means of producing cold. If you moisten the hand with any fluid which evaporates rapidly, you will at once feel the sensation of cold produced. If you move the hand about briskly in the air, so as to hasten the evaporation, the sense of coolness will be increased in proportion. The more rapid the evaporation, the greater the feeling of cold which is caused by it; and chemists even employ this means to produce the freezing of water or other liquids.

The surface of the skin, accordingly, is constantly cooled; first, by contact with the atmosphere, and, secondly, by the evaporation of its own fluids. In cold weather, however, the perspiration is in exceedingly small quantity. Its evaporation is not sufficient to chill the surface, and the temperature of the body is therefore kept up to its natural standard.

But in warm weather the perspiration is more abundant. The skin becomes active under the stimulus of the heat, the blood circulates more freely in the perspiratory glands, and a larger quantity of fluid is exuded upon the skin. Now, therefore, the perspiration sometimes becomes visible, because it is secreted more rapidly than it can be carried off by evaporation. The evaporation of this increased quantity of fluid produces, of course, a greater cooling effect. Consequently, in the sensibility of the skin and its perspiratory glands, the body possesses an apparatus for regulating its own temperature, notwithstanding the variations of the external atmosphere.

The regulation of the heat of the body by the skin is nearly as important as its production. For if the blood be actually heated much above its natural temperature,

death follows as certainly as if it had been cooled down below it. There are only a few degrees of variation above and below 100 Fahrenheit within which life can be maintained. Now whenever we make any unusual muscular exertion the body becomes warmer, probably because all the vital changes which produce heat then go on with greater rapidity. But, at the same time, the circulation in the skin is excited, and an abundant flow of perspiration thus prevents the heat from becoming excessive.

107. **Quantity of the Perspiration.**—The skin, there fore, is in constant activity; and whenever the temperature rises beyond a certain point, this activity is increased, and the cutaneous exhalation becomes more abundant. The average quantity of water discharged in this way with the perspiration is very nearly two pounds per day.

108. **Solid Matter secreted by the Skin.**—The watery parts of the perspiration, as we have seen, are carried off by evaporation. But its solid ingredients remain behind, and are deposited upon the surface of the skin. There is also another cutaneous secretion which is less abundant than the perspiration, and which serves to keep the skin soft and pliable. It is called the "sebaceous" matter. It is to a great extent oleaginous in its nature; and its solid ingredients, like those of the perspiration, remain deposited upon the surface.

109. **Necessity for general Ablution.**—Accordingly, it is of the greatest importance to keep the skin cleansed of these accumulations by frequent ablution. Not only those parts which are exposed to the contact of external impurities, but the whole surface of the body, should be frequently washed, in order to remove the debris of

its own secretions. The contact of cold water also acts as a healthy stimulus to the skin itself, and tends to preserve it in a vigorous condition, ready at all times to perform its natural functions.

QUESTIONS FOR CHAPTER X.

1. What is the *temperature* of the internal parts of the body?
2. Does this temperature vary with different climates, or remain the same?
3. How is the temperature maintained independently of the external air?
4. Do all animals produce heat more or less?
5. Which are called "warm-blooded" and which "cold-blooded" animals? and what is the difference between them?
6. Is the body kept warm by external temperature or by its own internal heat?
7. How does clothing, etc., serve to maintain the warmth of the body?
8. Is animal heat necessary to life?
9. What follows when the blood and internal organs are cooled down below their natural temperature?
10. How is the internal heat of the body produced?
11. Is it exactly the same in the different internal organs?
12. If not, how much does it vary?
13. How is the animal heat disseminated and equalized throughout the body?
14. Is the interior of the body any warmer in summer than in winter?
15. By what is the heat of the body moderated in warm weather?
16. What are the glands which produce the perspiration, and what is their structure?
17. What is the length of each glandular tube?
18. What is the combined length of all the perspiratory glands?
19. What are the ingredients of the perspiration?
20. Is the perspiration secreted occasionally or constantly?
21. What becomes of it after it is exuded upon the skin?
22. What is the effect of evaporation upon the warmth of the skin?

23. When is the perspiration "*insensible*," and when does it become visible?

24. What becomes of the solid parts of the perspiration when its watery portions are evaporated?

25. What is the *sebaceous matter* of the skin, and what is its use?

26. Why is frequent washing of the body necessary to health?

CHAPTER XI.

NUTRITION.

Definition of Nutrition.—Its three different Parts.—*Assimilation.*—Absorption of Inorganic Ingredients.—Their different Proportions in the Tissues and the Blood.—Different kinds of Albuminous Ingredients.—Transformation of the Albumen.—*Secretion.*—Structure of a Gland.—Follicles.—Lobules.—Ducts.—Inorganic Ingredients of a Secretion.—Its Albuminous Ingredient.—Increase of Secretion with excitement of the Circulation.—*Excretion.*—Alteration of Animal Tissues during Life.—A necessary consequence of Activity.—New Substances so produced.—Carbonic Acid.—Animal Vapors.—Urea.—Creatine.—Creatinine.—Urate of Soda.—Double Movement of Nutrition.—Supply and Discharge.—Quantity of Material absorbed and discharged in twenty-four hours.

By the term Nutrition we mean more especially all those secret and varied changes of substance which are constantly going on in the interior of the body, and which are essential to its life and organization. We shall find that these changes are of three different kinds, each of them necessary, in a different way, to the continued operation of the whole. They are, 1st, Assimilation; 2d, Secretion; and, 3d, Excretion.

110. **Assimilation.**—Assimilation is the formation of the tissues from the elements of the food. For the tissues of the body are all different in their composition from the substances which we take as food, and can only be formed when the elements of the food are made like, or "assimilated" to them. It is this process which we shall study in the first place.

We have already seen how the ingredients of the food are changed in the process of digestion, and how these substances, again, are converted into the materials of the blood. We may then say that they have been assimilated to the blood; for this fluid has now its particular ingredients, produced by the absorption and transformation of the digested food.

But this food is not yet converted into the tissues. None of the tissues have the same composition as the blood, and they are all different from each other; and yet they all depend exclusively for their materials upon the blood, which must supply them with every thing needed for their growth and organization. How is their nourishment, therefore, to be accomplished?

The fluid parts of the blood consist, as we remember, first, of water, with mineral substances in solution, which form its inorganic ingredients; and, secondly, of albumen and fibrine, which are its organic elements. Now all the inorganic substances have been derived from the food. They were absorbed from without, and now, consequently, form a part of the blood. They also exist in all the solid tissues. Some of them, like the chloride of sodium, or common salt, are every where in the body, no tissue being without them. Others, like the phosphate of lime, are sometimes in great abundance, as in the bones and teeth, where this substance forms more than half the entire tissue. When the blood, accordingly, freighted with these inorganic materials, arrives at the capillary circulation, penetrating every where into the interstices of the tissues, it gives up to them the substances necessary for their growth, by exuding them through the walls of the blood-vessels.

But here we meet with a singular phenomenon.

111. Deposit of Ingredients in different Proportions.—These inorganic substances are present in all the tissues in different proportions. The lime, for example, which in the bones constitutes over five hundred parts in a thousand of their tissue, in the cartilages forms only forty parts, and in the muscles only two parts and a half. Water, which in the teeth is only ten per cent. of their substance, in the brain is more than seventy-eight per cent. Each tissue also must contain these substances in its own proper proportion. If the lime, for example, were deficient in the bones, they would yield and bend under the weight of the body; and if it were in excess in the substance of the heart, the organ could not perform its function, and the circulation would come to an end.

Each tissue, accordingly, selects from the blood its own due proportion of inorganic matters and appropriates them to itself. It is as if each one were endowed with a kind of instinct, by which it should take no more and no less than is useful for its organization. This property resides in the substance of the tissues themselves. We found, while studying in a former chapter the subject of "Absorption" and "Endosmosis," that each animal tissue will absorb certain fluids and solutions more readily than others, and that the same substance will be taken up in greater quantity by one membrane than by a different one. The same thing happens during the circulation in the living body. Thus each tissue absorbs from the blood its proper quantity of material, and preserves continuously its special composition.

Furthermore, many of these ingredients are in much larger proportion in the tissues than in the blood. The lime, again, which is over five hundred parts per thou-

sand in the bones, in the blood is only three parts in ten thousand. How can the blood, therefore, in which it is so scanty, supply it to the bones, in which it is so abundant?

It is owing to the rapidity of the circulation. The blood which has passed through the capillaries of an organ and given up to it its ingredients, is at once followed by a fresh and unexhausted supply; and as it moves through the rapid course of the circulation, it incessantly revisits the different parts of the body, and continues, little by little, the contributions necessary for their support.

112. **Transformation of the Albuminous Matter.**—But we now come to the organic or "albuminous" ingredients of the body.

These are of the most varied character. In the muscular fibres the albuminous ingredient is termed "Musculine," and has peculiar chemical qualities. In the bones it is called "Osteine," in the cartilages "Chondrine," in the hair and nails "Keratine," and in the transparent lens of the eyeball "Crystalline." These substances are all solid in consistency, and nearly every tissue contains one peculiar to itself. And yet they are all supplied from the blood, which contains only two, namely, albumen and fibrine, neither of which forms the substance of any of the tissues.

Here, then, we have a phenomenon of transformation. As the albumen of the blood passes through the capillaries of each tissue, it is transuded and absorbed like the inorganic materials. But, unlike them, it is at the same time changed in character. In one tissue it becomes osteine, in another musculine, in another chondrine, and the like. This transformation is effected by

catalysis; that is, the constituent of each tissue has the power, simply by its contact, of converting the albumen of the blood into its own substance, and thus providing for its own regeneration.

It is in this way that the various tissues preserve their natural constitution. It is by this miraculous transformation, which is daily going on in the interior of our frame, and by which the gluten of bread, the caseine of milk, and the albumen of eggs are at last converted into the flesh, the bones, the membranes, and the nervous tissues of the human body. Through the intermediate action, therefore, of digestion and the blood, all the ingredients of the food are finally assimilated to the substance of the various tissues.

113. **Secretion.**—The second part of the nutritive process is *Secretion.*

A secretion is a fluid prepared from the blood by various internal organs, in order to accomplish a certain purpose in the animal economy. We have already had occasion to speak of several of these secretions, and to describe the office which they perform. Thus the gastric juice, secreted in the stomach, assists in the digestion of the food. The bile, formed by the liver, goes through certain changes in the intestine for the production of other materials. The perspiration is poured out upon the skin to regulate its temperature by evaporation. There are various other secretions which have not yet been mentioned, such as the tears, which moisten and protect the transparent surface of the eye; the milk, which serves for food to the young infant; and the mucus, which lubricates the internal passages of the body. Each one of these fluids serves for some definite and useful end in the vital operations.

114. Structure and action of the Secreting Organs.—The secretions are formed in certain organs, which consist of little cavities or "follicles," each one opening by an external orifice. Several follicles are usually grouped together, with all their mouths opening into a little tube, thus forming a "lobule;" and a number of lobules are also united into a compact mass, with their various tubes all joining into one common tube or "duct" (Fig. 42). Such an organ is called a *Gland.*

Fig. 42.

Structure of a Gland.

Sometimes the little cavities or follicles have the form of slender tubes, which open separately, each one by itself, as in the tubules of the stomach, the follicles of the intestine, and the perspiratory glands of the skin; but all the larger glandular organs, such as the parotid gland, the pancreas, and the milk glands, have the structure above described.

The capillary blood-vessels penetrate between these follicles, and bring the blood into minute contact with every part of the gland.

Now a change takes place in the glandular organ somewhat like that which we have described in the tissues. The blood, under the pressure of the circulation, parts with its water and its inorganic ingredients, which

transude through the blood-vessels into the cavities of the glandular follicles. Thus a fluid is produced from the ingredients of the blood, which is withdrawn or separated from the circulation, and is therefore called a "Secretion."

But each gland separates the ingredients of the blood in especial proportions, which are different for each secretion. Thus some secretions have a large quantity of water, like the perspiration; others a large proportion of solid material, like the pancreatic juice. For this peculiar constitution they depend upon the power of the gland to appropriate their materials in the proper quantity.

But in each secretion there is also a peculiar animal substance which does not exist in the blood, and it is usually upon this that the especial character of the secretion depends. Thus in the gastric juice there is pepsine, which serves to dissolve the food; in the saliva, the viscid substance which assists in mastication; in the milk, the caseine which gives it its nourishing quality. Now all these substances are produced in the gland itself. This is again a transformation, by which the albumen of the blood assumes a new form in the cavities of the glandular organ. The secretion, therefore, consists of this new substance, manufactured in the gland, together with the water and mineral ingredients which have been supplied directly by the blood.

The peculiar fluid thus produced is poured into the glandular follicles, and fills their cavities. It then appears in the tubes leading from the follicles, and, accumulating constantly in this way from behind, is finally discharged from the main duct or outlet of the gland.

We see, accordingly, how it is that these secretions

are produced more abundantly at particular times. When the circulation in the gland is excited, more blood is admitted to its capillaries, and its materials are supplied in greater quantity. They then exude rapidly into the glandular follicles, and pass out by its tubes and ducts in an abundant flow. When the circulatory excitement subsides, the production of fluid is again checked, and the gland is restored to a condition of repose.

115. **Excretion.**—Lastly, we have to study the process of *Excretion*.

In all our machines and mechanical contrivances we can make use of power only by the expenditure of material. Every mill must not only have a canal to supply it with water from above, but a sluice-way to carry off the waste water from below. The fuel of a furnace is constantly consumed, and afterward discharged in the form of smoke and ashes. The piston of a steam-engine is driven by the expansive force of the steam; but when the steam has once acted in this way, it has lost its power. In expanding it has changed its form, and must then be expelled from the cylinders to make room for a fresh supply.

The same thing happens in the living body. Every animal organ and tissue is altered and decomposed by its own activity. At every pulsation of the heart a portion of its vital power is expended, and the substance of its fibres changed. Every time the nerves feel, at the same moment their tissue is wasted and their sensibility more or less impaired.

This is not, however, a destructive or injurious action; it is the natural and healthy operation of the living organs. For it is by this very alteration of their

substance that they perform their work; and fresh material is at the same time constantly supplied for their renovation. It is as if nature were incessantly employed in unweaving and reconstructing the texture of the body, so that it may be always new, and always endowed with undiminished vitality.

116. **Substances produced by Excretion.**—But in this process new substances make their appearance in the body. As the changes which we have just described go on in the depths of the tissues, their ingredients are decomposed and appear under other forms. These substances represent the used or exhausted elements of the frame, and accordingly, from the first moment of their production, they are destined to be expelled. Their evacuation or elimination from the body is no less important than the other changes of nutrition; for by remaining, they would interfere with the vital powers and obstruct the activity of the system. It would be of little use to supply a furnace with fresh fuel, if it were to remain clogged with the ashes and cinders of the old.

Excretion is the process by which these waste materials are eliminated, and the substances so eliminated are termed the "excretions."

The most important and abundant of them all is *Carbonic acid.* We have already seen how constantly this substance is formed in the body, and how rapidly it is discharged by the lungs. It passes to the lungs with the liquid ingredients of the blood, and is there exhaled in a gaseous form by the breath.

At the same time, there is a small quantity of *Animal vapor* discharged in respiration. This vapor has no name, but it is that which gives a peculiar odor to the breath. So long as the breathing is unconfined and

ventilation free, we do not perceive it to any great extent; but in the confined atmosphere of a crowded and ill-ventilated room it at once becomes perceptible by its stifling and offensive odor. Though in comparatively small quantity, there is reason to believe that this substance is even more deleterious to health than the carbonic acid which accumulates at the same time. It is undoubtedly through this vapor of the respiration that contagious diseases are communicated, when the two persons who are affected have never been in actual contact, but have only breathed the air of the same apartment.

An odoriferous matter of similar nature is also exhaled with the *perspiration*. Like the former, it is in minute quantity, and is only injurious when allowed to accumulate and stagnate in the atmosphere. If carried away by ventilation, it is soon destroyed by the oxygen of the air, or decomposed by vegetables for their own nutrition.

117. **Urea.**—Another very important and abundant material of excretion is *Urea.*

Urea is a crystallizable substance which is produced in the body usually to the amount of rather over one ounce per day. We do not yet know in what particular parts of the system it is formed, but it makes its appearance every where in the blood, dissolved in its liquid ingredients. The quantity of urea produced varies somewhat with the activity of the body; for experiments have shown that it is increased by muscular exertion, and diminished during the periods of repose. Even mental application alone, without bodily effort, will be indicated by the increased amount of this substance formed in the system.

In some diseases the urea accumulates in the blood beyond its natural proportion. It then produces very injurious effects, and acts upon the system like a poison. The senses become deranged, and the circulation is impeded; and if the accumulation continues, it at last produces convulsions, insensibility, and death.

But in health the urea is constantly discharged from the blood by the kidneys. As the blood passes through the capillaries of these organs, its urea filters away, and it returns cleansed and purified to the circulation. Thus, as the carbonic acid produced in the body is expelled from the lungs, so the urea is expelled by the kidneys. It accumulates in their passages together with other watery and inorganic ingredients of the blood, and is finally discharged altogether from the system.

There are various other substances of a similar nature which pass out from the blood by the same channels with the urea. Two of them are termed *Creatine* and *Creatinine.* They are formed first in the muscles, and are absorbed from them by the blood. Another is termed *Urate of soda*, because its peculiar animal ingredient is combined with soda at the time of its formation. All these substances are expelled from the body, during health, nearly as fast as they are formed.

Next to the lungs, therefore, the kidneys are the great organs of purification for the blood. By them its waste and exhausted materials are incessantly removed, while its other ingredients are retained in their due proportion.

118. **Renovation of the Materials of the Body.**—We see, then, that the nutrition of the body is accompanied by *a double movement of supply and discharge;* and neither

of these two processes can go on independently of the other. Intermediate between the two is a third movement, namely, that of *secretion;* but most of the secreted fluids, after being once separated from the blood, are again absorbed by the blood-vessels, and so re-enter the circulation.

Now, if we examine the entire quantity of the materials thus absorbed and discharged every twenty-four hours, we can form an estimate of the rapidity with which the vital operations go on. We have already given the daily quantities of many of these substances; those of the remainder are added in the following list. The numbers are all given for a man of ordinary stature, weighing 140 pounds. In the first column is placed the quantity of material absorbed, in the second that of the material discharged.

Absorbed during 24 hours.		Discharged during 24 hours.	
Oxygen	1.02 lbs.	Carbonic Acid	1.53 lbs.
Water	4.73 "	Vapor from the lungs	1.15 "
Albuminous matter	.40 "	Perspiration	1.93 "
Starch	.66 "	Water of the Urine	2.02 "
Fat	.22 "	Urea and other excretions	.40 "
Mineral Salts	.04 "	Mineral Salts	.04 "
	7.07		7.07

Rather more than seven pounds of material, therefore, are absorbed and discharged daily by a healthy full-grown man; and, for one having the average weight of 140 pounds, a quantity equal to the weight of the whole body is thus taken into the system and expelled from it in the course of twenty days.

It is plain, also, that this material does not simply pass through the system, like water through a sieve. On the contrary, it actually combines during its pas-

sage with the ingredients of the tissues, and forms for the time a part of their substance. A large portion of it also suffers chemical transformations two or three times over, under the influence of the vital actions, passing successively through different forms, until it is finally discharged in the process of excretion.

Thus the history of nutrition is one of incessant change; by which the various ingredients of the body are continuously destroyed and renewed, while the body itself remains always vigorous and unaltered.

QUESTIONS FOR CHAPTER XI.

1. What are the three processes of nutrition?

2. What is *assimilation?*

3. Upon what fluid do the tissues depend for their nourishment?

4. Does the blood contain all the watery and mineral ingredients of the tissues?

5. Does it contain them in the *same proportion* as they exist in the tissues?

6. Do these substances exist in the various tissues in the same proportion or in different proportions?

7. Name some instances of the varying proportion of inorganic ingredients in the different tissues.

8. How are these substances deposited in their proper proportion in each tissue?

9. How can the blood supply more water or lime to a tissue than it contains itself?

10. Does the blood contain any of the "albuminous" ingredients of the tissues?

11. What are the albuminous ingredients of the blood?

12. Name some of the albuminous ingredients of the tissues.

13. How are the albuminous ingredients of the blood converted into those of the tissues?

14. What is a *secretion?*

15. Name some of the secretions and their uses.

16. Describe the structure of a *gland.*

17. What are its *follicles?* its *lobules?* its *duct?*

18. What is the arrangement of the capillary blood-vessels in a gland?

19. From what source are the watery and mineral ingredients of a secretion supplied?

20. How is its animal substance produced?

21. How are the secretions produced more abundantly at particular times?

22. What is the last of the processes of nutrition?

23. Do the organs of the body remain the same, or are they changed by the performance of their functions?

24. Is this change a destructive or a healthy process?

25. How are the organs maintained in a healthy condition?

26. What is an *excretion?*

27. Why must the excretions be discharged from the system?

28. What is the most abundant and important of all the excretions?

29. How is it discharged?

30. What other excretion is discharged with the breath beside carbonic acid?

31. When do the odoriferous matters of the breath and perspiration become deleterious?

32. What is *urea?*

33. How much urea is produced in the body per day?

34. When urea accumulates in the blood in disease, what effect does it produce?

35. By what organs is it discharged from the system during health?

36. What other excretions are discharged by the kidneys?

37. What is the entire quantity of materials absorbed and discharged by the body in twenty-four hours?

38. Does this material simply pass through the body, or is it combined with the tissues and again decomposed?

39. How long would it take for the whole substance of the body to be renovated by nutrition?

Section III.

THE NERVOUS SYSTEM.

CHAPTER XII.

GENERAL STRUCTURE AND FUNCTIONS OF THE NERVOUS SYSTEM.

United Action of the Organs.—System of Telegraphs.—Nervous Filaments.—Nerves.—Spinal Cord.—Spinal Nerves.—Brain.—Cerebrum.—Cerebellum.—Medulla Oblongata.—Cranial Nerves.—Nervous Fibres are Organs of Communication.—Irritability of Nerves.—Sensitive Fibres.—Motor Fibres.—Nerve Cells.—Nervous Centres.—Reflex Action of the Nervous System.

119. **Object and Use of the Nervous System.**—In the foregoing chapters we have studied the manner in which each different organ of the body performs its work. We are now about to see how they are made to act in harmony with each other, for the benefit and support of the whole.

For it is not enough that an organ be made capable of performing a certain function; it must also act *at a particular time and in a particular manner.* How is it that the diaphragm moves upward and downward just often enough to supply the lungs with the air needed in respiration? The stomach, as we have seen, secretes its gastric juice precisely when this is required for the digestion of the food, and not at other times. The varying currents of the circulation, the action of the glandular organs, and even the movement of the limbs, must all work together, or alternately, in such a way as not to interfere with each other, but to assist harmoniously in the general functions of the bodily frame.

This harmonious action of the different organs is se-

cured by the aid of the *Nervous System.* What is the structure of the nervous system, and how does it perform its work?

120. **General Arrangement of the Nervous System.**—Imagine a series of telegraph wires running from all the police stations of a great city to the central office or head-quarters of the department. These wires form a communication between every street, lane, and avenue of each district and the central office, and again between the central office and all parts of the city. Any thing which happens in one district may be telegraphed to head-quarters, and an answer at once returned, giving the necessary orders or sending the required assistance. If a man is found sick or wounded, surgical aid is dispatched to his relief. If a larger number of policemen are required to quell a disturbance, or to perform any unusual duty, they are ordered from other districts and collected at the proper point by the same means of communication. Thus the whole machinery of the department acts together or separately, as occasion demands, and its different parts move constantly in harmony with each other.

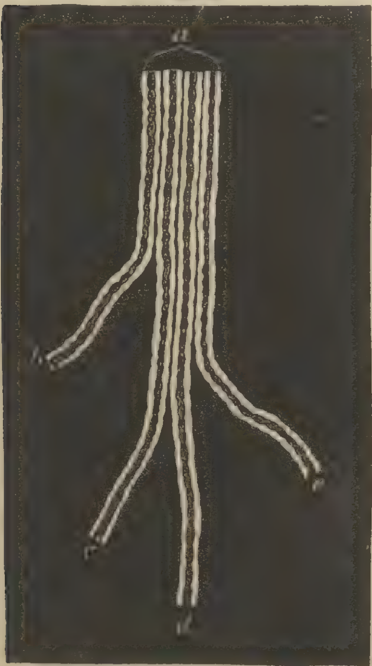
The nervous system is such a means of communication between the different parts of the animal frame.

121. **Nervous Fibres or Filaments.**—Throughout the body there are distributed a multitude of slender white threads or filaments, which run in every direction, interlacing themselves with the various tissues, and reaching every part of the skin, the muscles, and the glandular organs. These filaments are of extreme delicacy, the smallest of them measuring only $\frac{1}{10000}$ of an inch in diameter, and the largest not more than $\frac{1}{2000}$ of an inch. Each one is composed of a fine gray ribbon-

like thread in the centre, which is surrounded by a white, soft material, very nearly like thickened cream in consistency (Figure 43), the whole being inclosed in a thin, transparent covering, or tubular membrane. The filaments so formed are called the *Nervous filaments.*

At their commencement, the nervous filaments, as we have said, are disseminated among the tissues of the various organs. From these points they approach each other, uniting, side by side, into little bundles. As these bundles emerge from the different parts of an organ they also join each other, and form larger cords by the continued association of other filaments. When such a collection has become large enough to be seen by the naked eye, it is called a *Nerve.*

Fig. 43.



Different Nervous Filaments uniting to form a nerve; highly magnified: *a.* portion of nerve; *b, c, d, e.* Nervous filaments.

Each nerve, accordingly, is a bundle of such filaments, collected from different parts, and all running in the same direction. These filaments do not unite or become confounded with each other in the substance of

the nerve, but remain distinct, like the separate threads in a skein of silk (Fig. 43).

When a nerve has thus disengaged itself from the deeper textures, and begins to run in the interstices between the adjacent parts, it becomes invested with a thin but strong covering of white fibrous tissue, which binds together and protects its separate filaments. For these filaments, composed of the soft and delicate material which we have described, would be liable to injury or laceration by the movement of the limbs and the pressure of more solid organs, were they not protected by such an investment. This fibrous covering of the nerve is called its "neurilemma," or *Sheath.* It gives to the nerves that white and glistening color by which they are recognized by the surgeon in his dissection of the various parts.

The nerves originating in the skin and muscles of the different regions of the body, and from the upper and lower limbs, pass inward, from the right side and the left, toward the situation of the median line and the spinal column. Arrived in this neighborhood, they form thirty-one distinct pairs, each pair consisting of two symmetrical nerves, one right and one left, coming from the corresponding sides of the body. They then pass through certain openings in the sides and back part of the spinal column, and thus penetrate into the cavity of the spinal canal. Here they unite into a long, white, cylindrical nervous mass, running from below upward directly along the middle line of the back, in the cavity of the spinal canal. This nervous mass is the *Spinal cord.*

The spinal cord, therefore, contains within itself the filaments derived from all the nerves of the external parts of the body and limbs. As these nerves unite

with the spinal cord in the manner above described, they are called the *Spinal nerves.*

The substance of the spinal cord is soft and delicate; but it is defended by the solid mass of the spinal column in front, and by its bony prominences, which arch over and embrace the spinal cord at the sides and behind. It is thus inclosed in a long cavity or canal, which we have already mentioned under the name of the "spinal canal." The spinal cord passes through this canal from below upward until it reaches the upper extremity of the spinal column. Here it enters the cavity of the cranium, and at once expands into a large rounded nervous mass, which is the *Brain* (Fig. 44).

Fig. 44.

The Brain, Spinal Cord, and Spinal Nerves, seen from behind.—1, 2. Brain, consisting of, (1), the Cerebrum, and, (2), the Cerebellum; 3. the Spinal Cord and Nerves; 4. Nerves of upper limbs; 5. Nerves of lower limbs.

The brain itself consists of three parts, viz., 1st, an upper, larger, and more rounded mass, covered with sinuosities or convolutions, which fills all the upper, middle, and anterior portion of the skull, called the *Cerebrum;* 2d, a smaller and more flattened portion, also convoluted upon its surface, situated at the lower and back part of the skull,

called the *Cerebellum;* and, 3d, a still smaller portion, placed at the junction of the spinal cord with the brain, and called the *Medulla oblongata.* In the preceding figure the medulla oblongata is not shown, because it is concealed by the larger masses of the cerebrum and cerebellum.

Both the brain and the spinal cord, furthermore, are divided by a deep furrow into two equal parts, right and left. These portions are joined to each other beneath by connecting masses of nervous substance; but upon their surface, especially when seen from behind, as in Fig. 44, they present the appearance of two separate halves, corresponding to the two sets of nerves coming from the opposite sides of the body.

Beside the nerves connected with the spinal cord, there are various other pairs, supplying the parts about the head and neck, which reach the brain by passing through openings in the lower part of the cranium. They are called the *Cranial nerves.* They are not represented in the preceding diagram, as they pass, for the most part, in a direction from behind forward, and from before backward.

Thus the main part of the nervous system, as above described, consists of, 1st, the Nerves coming from the various parts of the body; and, 2d, the Brain and Spinal cord, with which these nerves are united.

Now *the nervous filaments are the fibres of communication of the nervous system.* They are the telegraphic wires through which its secret messages are sent from one part of the bodily frame to another. How is it that they perform this office?

122. **Irritability of the Nervous Fibres.**—Each nervous fibre is endowed with a peculiar power, which is called

its *Irritability.* By this we mean that whenever it receives a certain impression, every portion of it is roused into a peculiar state of activity or excitement. What is the precise nature of this activity of the nervous filament we do not know; but we know that it is instantly propagated through its substance from one extremity to the other. If you strike one end of a bar of iron, the metal vibrates throughout its entire length. Somewhat in a similar way, when the proper stimulus is applied to one extremity or any part of a nervous fibre, the whole of it is thrown into simultaneous excitement.

Now this activity of a nervous fibre does not produce any visible effect in the nerve itself. Its peculiar quality is that it *calls into activity some other organ.* Thus the muscles are made to contract, or the glands are excited to secretion by the stimulus of the nerves; and yet the nerves which convey this excitement do not themselves show any change in their appearance. They serve to communicate the stimulus which is to produce its effect elsewhere.

123. **Two different kinds of Nervous Fibres.**—But when we closely examine the nervous fibres, they are found to be of two different kinds, endowed with two different functions.

The first are the *sensitive* fibres. They are distributed throughout the skin, the lining membranes, and other organs of the body. They are so called because they are sensitive to the impressions made upon these organs; and they communicate the impressions thus received to the central parts of the nervous system. They transmit the nervous excitement, therefore, in a direction from without inward.

The others are the *motor* fibres. They are so called because they call into motion or activity the muscles or other organs to which they are distributed. They act, accordingly, in a direction exactly contrary to the former, and transmit the nervous stimulus from within outward.

124. **Nervous Centres, or Ganglia.**—But the wires of a telegraphic system would be useless in themselves unless they were connected with a telegraph office or station, where their messages could be received, and from which the necessary answers could be returned. There are such telegraphic stations in the nervous system.

Beside the white nervous matter, formed of the filaments or fibres already described, there is another kind of nervous tissue, called the "gray" or "cineritious" matter. As its name indicates, it is of a gray or ashy color; and it contains, beside nervous fibres and blood-vessels, a great abundance of microscopic bodies, of various forms, which are called the "nerve-cells." These cells are the peculiar elements of the gray nervous matter, and are not found elsewhere. They are generally more or less rounded in form, with an oval spot upon each, which is called its "nucleus." Many of them have slender projections or elongations running out from the surface in various directions (Fig. 45). The nerve-fibres are abundantly mingled and interwoven with the cells, and often, if not always, communicate with

Fig. 45.

Nerve-cells; highly magnified. From a ganglion.

them by means of the slender prolongations above spoken of. Such a collection of gray nervous matter is said to be a "ganglion."

The gray matter forms a large part of the structure of the nervous system. It is found in the interior of the spinal cord, running in a double tract through its central parts, from one extremity to the other, being covered by the white fibres on its exterior. In the brain, on the contrary, it is spread out upon the surface, forming the folds and convolutions; and it is also distributed in several different masses in the deeper and inferior parts. The brain and spinal cord may therefore be considered as a collection of ganglia, added to the mass of white fibres coming from the nerves.

Now the ganglia are what are called the *Nervous Centres.* That is, the sensitive fibres terminate in them, and the motor fibres originate in them. We have already said that these fibres are only organs of communication. But the nervous centres are the organs which receive the sensitive impressions from without, and which originate the nervous action from within. They receive intelligence by the sensitive fibres from the distant membranes; and by the motor fibres they send out in return the stimulus which calls into activity the muscles or the glands.

125. **Reflex Action of the Nervous System.**—Thus the nervous centres are intermediate in their function between the sensitive and motor fibres. The stimulus conveyed from without inward is received by them, and then returned or reflected in the opposite direction. This action is called the *Reflex Action of the nervous system.*

This term expresses the whole secret of the nervous functions.

We see, accordingly, how it is that the nervous system acts as a means of communication between different organs. This communication is not direct, but circuitous in its action. It passes first inward to the nervous centres, and again outward by reflection to the external organs.

By the operation of the nervous system, also, we find that *a stimulus applied to one organ excites the activity of another.* Thus cold applied to the skin produces a contraction of the muscles; food introduced into the stomach causes the evacuation of the gall-bladder; and an irritating substance in the throat excites coughing by the muscles of the abdomen.

Thus the different organs are associated in their function, and made to act together, separately or in succession, as the requirements of the system may dictate.

There are a considerable number of nervous centres, which preside over different functions, and which receive and communicate stimulus of different kinds. We shall now proceed to study in succession these various departments of the nervous system.

QUESTIONS FOR CHAPTER XII.

1. Why must the different organs act *in harmony* with each other?
2. By what system is the harmonious action of the organs secured?
3. What is the structure, size, and appearance of the *nervous filaments?*
4. What is a *nerve?*
5. By what are the filaments of a nerve bound together and protected?
6. In what part of the nervous system do the nerves of the body and limbs terminate?
7. What is the situation and form of the spinal cord?
8. With what is the spinal cord connected at its upper extremity?
9. In what cavity is the brain contained?

10. What are the three principal parts of the brain?

11. By what are the two lateral halves of the brain and spinal cord separated from each other?

12. What are the *spinal nerves?* what are the *cranial nerves?*

13. What is the general function of the nerves and nervous filaments?

14. What is the *irritability* of a nerve?

15. Where is the effect of nervous irritability manifested—in the nerve itself, or in some other organ?

16. What two kinds of nervous fibres are there in the nervous system?

17. What is the property of the *sensitive* fibres?

18. What is the property of the *motor* fibres?

19. What is the structure of the *gray nervous matter?*

20. What is the name given to a collection of gray nervous matter?

21. Where is the gray matter situated in the spinal cord? in the brain?

22. What is the function of a ganglion?

23. What is the *reflex action of the nervous system?*

24. Name some instances of reflex action.

CHAPTER XIII.

THE SPINAL NERVES AND SPINAL CORD.

Function of the Spinal Nerves.—Sensation and Motion.—Paralysis from injury of Nerve.—Restoration of a divided Nerve.—Anterior and Posterior Roots of Spinal Nerves.—Anterior Roots motor.—Posterior Roots sensitive.—Anterior and Posterior Columns of the Cord.—Anterior Columns motor.—Posterior Columns sensitive.—Connection of Spinal Cord with Brain.—Paralysis from injury of Spinal Cord.—Paraplegia.—Crossed Action of the Spinal Cord.—Hemiplegia.—Intercostal Nerves.—Phrenic Nerve.—Sensibility of the Skin—its Variation in different Parts.—Ordinary Sensibility.—Sensibility to Pain.—Sensibility to Heat and Cold.—Spinal Cord as a Nervous Centre.—Its Gray Matter.—Reflex Action of the Spinal Cord.—Its Character and Function.

126. **Distribution of the Spinal Nerves.**—The spinal nerves, as we have seen, which are distributed to the external surface and muscles of the body and limbs, place these organs in communication with the spinal cord, and, through the spinal cord, also with the brain.

Now these nerves are the organs of the two great functions of *Sensation* and *Motion.* If we touch any part of the external surface we feel the contact, because it is transmitted to the nervous centres by the nerve coming from the part. Whenever we move a limb, we do so by means of the nerve which calls into action the muscles to which it is distributed. These two functions, therefore, of sensation and motion, are confided to each nerve for that part of the body to which it belongs.

127. **Effects of injury to a Spinal Nerve.**—Consequently, when a spinal nerve is injured or destroyed, these functions can not continue. Such an effect is produced whenever the principal nerves of the arm or the leg are accidentally compressed so that their vitality is suspended. The limb is then said to be "asleep." It is numb and powerless, and seems like a dead weight attached to the body. When the pressure is taken off, the nerve gradually recovers itself, and sensibility and movement return in the affected limb.

The same effect is still more complete when a nerve is actually cut or torn apart. Then all communication is severed between the central parts and the injured limb. The muscles may be sound, but we can not use them, since the necessary stimulus can no longer reach them through the divided nerve. The skin may be uninjured, but we can not feel, because the nervous communication stops short before it arrives at the spinal cord. This affection is called *Paralysis.*

In such cases the paralysis, of course, is confined to that part supplied by the injured nerve. Thus, if the nerve going to one leg be cut off, that leg alone is paralyzed. If the nerve belonging to the right arm be divided, the right arm alone is affected. Any portion of the limb, such as the hand or even one finger, may be separately paralyzed, if the nerve distributed to it be severed while the others remain uninjured.

In such a paralysis it is evident that there are two different affections combined, namely, a *paralysis of motion* and a *paralysis of sensation.* Both kinds of paralysis are produced at once, because the nerve contains both motor and sensitive fibres, and because all these fibres have been cut off at the same time.

128. **Reunion of divided Nerves.**—Now, does an accident like this destroy all hope of cure, and entail a permanent loss of motion and sensibility in the injured parts? Fortunately it does not. If it were so, every surgical operation would produce more or less paralysis, and even every accidental cut upon the fingers would destroy the sensibility and action of some portion of them. For the smaller nerves are so finely distributed that some fibres are necessarily severed by any incision of the tissues, and after a time a repetition of such accidents would paralyze a considerable portion of the surface.

But these fibres, when cut, grow together again. They heal, like the muscles or the skin, and thus re-establish their communication. This healing of the nerves is slower and more difficult than that of other tissues, and therefore the surgeon avoids them in his operations. But after a long interval, sometimes several months or even a year, according to the size of the nerve, the wounded fibres gradually reunite, and sensibility returns to the surrounding parts.

In the spinal nerves of the limbs and trunk the sensitive and motor fibres are inextricably mingled together. They also have precisely the same structure, and we can not distinguish one kind from the other by any difference in their appearance. We only know that the nerve serves at the same time both for sensation and motion, and therefore that it contains both motor and sensitive fibres.

129. **Distinction of Sensitive and Motor Roots in the Spinal Nerves.**—But as the nerve enters the cavity of the spinal canal, a curious change becomes manifest in its anatomical arrangement. There the two kinds of fibres

part company. The sensitive fibres pass backward in a separate bundle, and join the spinal cord toward its posterior part; the motor fibres disengage themselves from the others, and unite with the spinal cord toward its front part. Thus every spinal nerve, on each side the body, has two separate roots, by which it is connected with the spinal cord, viz., a *posterior root*, composed of sensitive fibres, and an *anterior root*, composed of motor fibres (Fig. 46).

Fig. 46.

Transverse section of the Spinal Cord.—*a*, *a*. Spinal nerves of right and left side, showing their two roots: *d*. Anterior root; *e*. Posterior root; *c*. Ganglion of posterior root.

In the accompanying diagram, the spinal cord is shown in transverse section; that is, as if it were cut across horizontally at the level of one pair of spinal nerves. The lower part of the drawing represents the front of the spinal cord, and the upper part its posterior portion. The two roots of each nerve, anterior and posterior, are seen separating from each other, and uniting with the corresponding parts of the spinal cord. The posterior root has upon it a small swelling or ganglion (marked *c*), which is the only particular in which its appearance differs materially from that of the anterior root. The longitudinal fissure is also shown, by which

the spinal cord is partially divided into right and left halves. This fissure is rather wide and shallow at the front, but narrow and deep behind. Finally, the gray matter is seen in the central part of the spinal cord, showing the singular cross-like form in which it is arranged.

While in the nerves of the exterior, accordingly, the functions of motion and sensibility are mingled together by the interlacing of their fibres, in the central parts of the nervous system they are separated from each other and occupy distinct situations.

What becomes of the fibres of the nerves after they have been united with the spinal cord?

130. **Passage of Sensitive and Motor Fibres through the Spinal Cord.**—On arriving at the corresponding portions of the cord, they change their direction and pass from below upward. The sensitive fibres of the posterior roots then form a part of those two vertical bundles of white nervous matter which run up and down on the back of the spinal cord, on each side the central fissure. (See Fig. 44.) These are called the *Posterior columns of the cord.* The motor fibres of the anterior roots join two similar bundles of white matter in front; these are called the *Anterior columns of the cord.*

The posterior columns of the cord are sensitive, like the fibres of the posterior roots; and the anterior columns are motor, like the fibres of the anterior roots.

131. **Termination of Nervous Fibres in the Brain.**—From this point the anterior and posterior columns of the cord pursue their course to the upper part of the spinal canal. Here they enter the great opening or foramen in the base of the skull, and then, enlarging and spreading their fibres in various directions, termi-

nate, as we have already said, in the substance of the brain.

Throughout this distance the nervous fibres of the spinal cord maintain an undisturbed connection. Anatomists can not yet determine whether each filament by itself runs a continuous and uninterrupted course from the nerve to the brain throughout the spinal cord, or whether successive fibres connect with each other the nerve, the spinal cord, and the brain. For these filaments are so innumerable and so delicate that it is impossible to follow the same one under the microscope long enough to be sure of its exact destination. But, whatever may be their precise anatomical arrangement, the physiological connections of the anterior and posterior columns are continuous and complete up to the point of their termination in the brain.

Now the brain is the seat of the consciousness and the will. No sensation can be perceived until it arrives at the brain, and no voluntary motion can be performed unless the nervous stimulus, starting from the brain, can reach the nerve through the spinal cord.

The spinal cord, therefore, as thus far considered, is a medium of communication between the brain and the spinal nerves. It may be regarded itself as a great nerve, inclosed in the spinal canal and giving off the successive pairs of spinal nerves as branches from its own trunk.

132. **Paralysis from Injury of the Spinal Cord.**—Accordingly, any injury to the spinal cord will produce paralysis of the parts below. This happens where any severe accident has broken and displaced the bony arches of the spinal column which inclose and protect the cord. The broken pieces of bone, pressing upon

the cord and lacerating its substance, cut off the communication between the brain and the inferior parts. When such an injury has produced paralysis of the lower part of the body, we say of the paralyzed person that his "back is broken." The fracture of the bones, however, would not be, by itself, of much consequence, since it is only the projections on the back of the spinal column which are usually broken; but it becomes important and dangerous on account of the injury inflicted at the same time upon the spinal cord.

When such a fracture of the spine happens in the middle of the back, the legs are paralyzed, while the arms remain unaffected. This form of paralysis, which is confined to the lower half of the body, is termed *Paraplegia.* If the injury be in the middle of the neck, the arms are also paralyzed, since the spinal cord is then severed above the point at which the nerves to these limbs are given off.

In all such cases as the above, the powers of motion and of sensibility are usually paralyzed together. The skin becomes insensible, and the voluntary muscles powerless over the whole extent of the paralyzed parts; because so rude an injury to the spinal cord will generally reach all parts of its thickness, and tear off at the same time its sensitive and motor fibres. But sometimes it happens that the accident affects only the anterior or only the posterior portion of the cord. In such instances the power of motion is suspended while sensibility remains; or, on the other hand, the sensibility of the skin is lost while the muscles retain their power.

133. **Decussation of the Motor and Sensitive Fibres of the Spinal Cord.**—A singular feature in the connection

of the spinal nerves with the brain through the spinal cord is that this connection is a crossed one; that is, that *the nerves of the right side of the body are connected with the left side of the brain, and those of the left side of the body with the right side of the brain.*

The anterior columns of the cord pass upward, as we have seen, their fibres running nearly parallel with each other until they reach the entrance to the skull. Immediately above this point, and before joining the brain proper, the spinal cord enlarges into a somewhat wider and thicker oblong-shaped mass, which has been already mentioned, called the "medulla oblongata." At this situation the fibres of the two columns cross over obliquely from side to side, those of the left anterior column passing to the right side, and those of the right anterior column passing to the left side. This is called the "Decussation of the anterior columns of the cord." Their fibres then terminate respectively in the corresponding sides of the brain.

Thus each side of the brain holds under its control the voluntary movements of the opposite side of the body.

134. **Paralysis from injury of the Brain.**—The consequence of this is, that when a serious injury is inflicted upon the brain at the point where these motor fibres of the nerves take their origin, a singular kind of paralysis is produced, which is exactly confined to one side of the body. The right arm and the right leg, for instance, will be paralyzed, while the two limbs of the left side will remain uninjured. This kind of paralysis is known as *Hemiplegia.* It is situated on the opposite side of the body to that on which the injury to the brain has been inflicted.

The sensitive fibres of the spinal cord also pass from one side to the other. Their crossing, however, takes place, not in a particular spot, but throughout the whole length of the cord. As the sensitive root of each nerve joins the posterior column, its fibres soon pass over through the central portions of the cord, and then form a part of the posterior column of the opposite side. In hemiplegia, therefore, produced by injury of one side of the brain, the power of sensation is lost on the opposite side of the body, at the same time with the power of motion.

135. **Intercostal and Phrenic Nerves.**—Among the spinal nerves there are certain ones that deserve particular attention.

The first of these are the *Intercostal nerves.* As their name indicates, they are situated between the ribs, and are distributed to the intercostal muscles in the same situation. They are united with the spinal cord in the middle region of the back, from the level of the first rib to that of the last. It is these nerves, therefore, which enable the intercostal muscles to move in the act of inspiration.

Now, if we recall the mechanism of inspiration, we shall remember that this mechanism consists of two associated actions: first, the movement of the diaphragm, by which the abdomen is protruded below, and, secondly, the movement of the intercostal muscles, by which the chest is raised and expanded above. Both these sets of muscles are animated by nerves which come from the spinal cord; and the intercostal nerves, as we have seen, are given off from it in the middle region of the back.

Accordingly, if the spinal cord be injured at the level

of the first rib or at the lower part of the neck, the intercostal muscles are at once paralyzed. The chest no longer expands in respiration, but remains quiescent and motionless. It is for this reason that a fracture of the spine at the upper part of the back is more dangerous than when situated lower down. Nevertheless, the breathing does not stop altogether, since it is still partially kept up by the action of the diaphragm.

The other important pair of spinal nerves are the *Phrenic nerves*, which belong to the diaphragm itself. This nerve springs from the spinal cord by branches from two or three of the spinal nerves, just above the middle of the neck. Thence it passes downward as a single trunk on each side, and, entering the cavity of the chest, is distributed to the muscular fibres of the diaphragm. Upon the phrenic nerve depends the whole power of motion of this important muscle.

When the spinal cord, therefore, is severed above the middle of the neck, both the intercostal muscles and the diaphragm are paralyzed together. All the movements of respiration accordingly cease, and death is necessarily produced.

136. **Acuteness of Sensibility in different parts.**—Several facts remain to be noticed in regard to the *sensibility* conferred by the fibres of the spinal nerves.

This sensibility is extended throughout the skin or general integument of the body, and is therefore called the "General sensibility." It is not, however, distributed every where in an equal degree, but is much more acute in some situations than in others; being more highly developed than elsewhere in the tips of the fingers. Physiologists have sometimes measured the degree of sensibility of different parts; and have found

that at the tips of the fingers it is twice as great as at the middle of their under surface, five times as great as on the back of the fingers, nine times as great as on the back of the hand, seventeen times as great as on the top of the foot, and more than thirty times as great as in the middle of the back. It is for this reason that we generally use the fingers as the organs of touch; and also because by their varied movements we can easily adapt them to the different surfaces which we may wish to examine.

The sensibility of the skin is called into action by the contact of foreign bodies, and gives us information of their softness or resistance, their external shape, the smoothness or roughness of their surface, their fluidity or solidity, of cold and heat, and of all the physical qualities which can be ascertained by the touch.

The internal tissues, such as the muscles and some of the lining membranes, are also endowed with sensibility, but it is much less acute in them than in the skin.

137. **Sensibility to Pain.**—It is through the sensibility of these parts that we are capable of feeling pain. But it is a curious fact that the *sensibility to pain* is entirely distinct from ordinary sensation, and even interferes with it exactly in proportion as it becomes more acute. Thus, if we place the hand upon a piece of iron at ordinary temperatures, we can tell whether it is cool or warm, and can form a good idea of the exact degree of its cold or heat. But if it be hot enough to burn the skin, we no longer estimate the degree of its temperature, but only feel the pain which it occasions. It is for this reason, as it is commonly said, that bodies which are excessively hot or excessively cold produce the same

sensation. The truth is, they do not produce any sensation of cold or heat, properly speaking, but only a sensation of pain, which is different from either.

138. **Sensibility to Heat and Cold.**—Finally, the sensibility to heat and cold is different also from the ordinary sensibility of the touch; and instances have been known where persons have lost the power of distinguishing temperatures, while they have retained both the sensibility of touch and the sensibility to pain.

All these different kinds of sensation are communicated to the brain through the medium of the spinal nerves and the spinal cord.

So far, then, we have found the spinal cord to be an organ of communication between the spinal nerves and the brain; serving to conduct the power of sensation and voluntary motion by means of its anterior and posterior columns.

139. **The Spinal Cord as a Nervous Centre.**—But the spinal cord is also a *Nervous centre.* For it contains in its deeper parts a double band of gray nervous matter, in the form of a long ganglion running through its entire length. The form and situation of this gray matter may be seen in a transverse section of the cord, as in Fig. 46. The motor and sensitive fibres of the spinal nerves not only join its anterior and posterior columns, as already described, but they also communicate with the gray matter in its central parts. The spinal cord may therefore act independently, as a distinct ganglion.

When the cord is severed in the region of the neck or the upper part of the back, communication with the brain being cut off, all voluntary motion is lost in the muscles of the limbs below. But still these muscles may act; and they may act in response to a stimulus

applied to the skin of the paralyzed parts. This is sometimes seen in persons affected with complete paralysis of the lower half of the body. Such persons are entirely helpless and insensible in the lower limbs. And yet touching the legs or the soles of the feet, the impression of cold air, or the contact of the clothes, will often produce very evident twitching of the muscles, and even bending or straightening of the knees and ankles.

In these cases the patient has no feeling in the paralyzed parts, and no knowledge of the movements which they execute. The brain, therefore, has nothing to do with these movements. They are performed by the independent action of the spinal cord. Such movements, however, are reflex in their nature. That is, the action of the muscles is excited by a stimulus applied to the skin. The nervous stimulus is first conveyed inward by the sensitive fibres of the skin, and again reflected outward through the motor fibres to the muscles. This is called the *Reflex Action of the spinal cord.* How is this action accomplished?

When the stimulus applied to the skin is conveyed inward by the nerves, it arrives at the spinal cord by the posterior roots, and reaches the gray matter in its central parts. Here the gray matter receives the nervous impression, and instantly converts it into a motor impulse, which is reflected outward along the motor fibres of the anterior roots. As these fibres are finally distributed to the muscles, they stimulate these organs to contraction, and thus the reflex movement is finally produced (Fig. 47). In the accompanying diagram the spinal cord is shown in vertical section; that is, as if it were split longitudinally from above downward. The gray matter in its centre, therefore, ap-

Fig. 47.

Diagram of Spinal Cord in Vertical Section, showing Reflex Action.—*a*. Posterior root of spinal nerve; *b*. Anterior root of spinal nerve.

pears as a vertical band or ribbon, still covered with the white substance on its exterior. The direction of the nervous stimulus is also shown, as it passes inward by the posterior root to the gray matter, and is there turned or reflected back, to pass outward again along the motor fibres of the anterior root.

Now the peculiarity of this action of the spinal cord is that it is a perfectly simple reflex action; that is, *it is not accompanied by any sensation, consciousness, or volition.* These properties reside altogether in the brain, and do not belong to the spinal cord. Consequently, when the communication with the brain is cut off, it is only the simple blind operation of the cord itself which is called into activity.

140. **Importance of the Reflex Action of the Spinal Cord.** —But this independent action of the spinal cord takes place also in health, only we do not usually notice it, because our attention is not attracted by any conscious sensation. Nevertheless, it is very important in protecting the body from sudden injuries, and in regulating the action of some of the internal organs.

When the skin of any part is unexpectedly brought in contact with a foreign body, such as a heated iron or a rough surface, we often withdraw the limb by an instantaneous and involuntary motion before we are fairly conscious of any injury. This is the reflex action of

the spinal cord. In falling from a height, the limbs are instinctively thrown into such a position as to defend the most important parts of the body, and break as much as possible the force of the shock. This is the reflex action of the spinal cord. Certain of the internal muscles which guard the natural passages of the body are maintained in continuous contraction without voluntary effort and without fatigue, and are moved in various directions at the proper time, to provide for the healthy operation of the internal functions. This is also accomplished by the reflex action of the spinal cord.

When the sensibility or reflex power of the spinal cord is unnaturally increased, it produces diseases of a terrible character. These are the various affections which are accompanied by *Convulsions;* in which all the muscles of the body are thrown into involuntary spasms, and the limbs are bent and distorted by irresistible contractions. In the convulsions of infants, these movements are usually caused by indigestion. In the more fatal diseases of "Tetanus" and "Hydrophobia," in grown-up persons, the least external excitement, such as the opening of the doors, the contact of the dress, or a breath of air, is sufficient to call out the unnatural irritability of the cord, and throws the whole muscular system into spasmodic rigidity.

During health, accordingly, we are not conscious how much we owe to the spinal cord and its reflex power. Quiet and unnoticed, it keeps watch over the safety of the body, ready to act at an instant's warning, and performs its work without ever causing us fatigue, or requiring any effort of attention or of the will. But when, irritated by disease, it loses its character of moderation

and regularity, and from the servant of the body becomes its master, then it rapidly exhausts the muscular force and destroys life by the uncontrolled violence of its action.

The spinal cord, therefore, is not only a medium of communication between the brain and the external parts. It is also a nervous centre, which presides by itself over the involuntary movements of the body and limbs. It acts as such without our consciousness and independently of our will; and its function is to provide for certain muscular actions in the interior, and to protect the body against unforeseen dangers from without.

QUESTIONS FOR CHAPTER XIII.

1. How are the different parts of the body and limbs placed in communication with the spinal cord and the brain?
2. What are the two great functions of the spinal nerves?
3. What is the effect of compressing or cutting off a spinal nerve?
4. What is paralysis?
5. What two kinds of paralysis exist together after cutting off a spinal nerve?
6. May the nerve grow together again after it has been once divided? What effect does this have on the paralyzed parts?
7. What two kinds of fibres are contained in the spinal nerves?
8. How are the sensitive and motor fibres separated within the spinal canal?
9. How and where do they unite with the spinal cord?
10. Of what fibres is the *anterior* root of a spinal nerve composed?
11. Of what is the *posterior* root composed?
12. In what direction do the nervous fibres pass after joining the spinal cord?
13. What are the anterior and posterior columns of the cord, and what is the difference in their function?
14. What is the effect of injury of the spinal cord upon the parts below?
15. Why is fracture of the spine liable to produce paralysis?

16. What is *paraplegia?*

17. What part of the spinal cord must be injured to produce paraplegia?

18. What part of the spinal cord must be injured to produce paralysis of both arms and legs?

19. Are motion and sensation both suspended together in ordinary cases of paralysis?

20. Are they ever affected separately? Under what circumstances?

21. How are the two opposite sides of the body and brain connected with each other?

22. Where do the fibres of the anterior columns cross to the opposite side?

23. What is *hemiplegia?*

24. If the *right* side of the brain be injured, which side of the body will be paralyzed?

25. If the *left* side of the brain be injured, which side of the body will be paralyzed?

26. Where do the *sensitive* fibres of the spinal cord cross from side to side?

27. Where are the intercostal nerves united with the spinal cord?

28. What effect is produced on respiration by fracture of the spine at the upper part of the back?

29. By what nerves is the *diaphragm* supplied?

30. Where are the phrenic nerves united with the spinal cord?

31. What effect is produced on respiration by injury to the spinal cord above the origin of the phrenic nerves?

32. What is "*general sensibility?*"

33. In what parts is the sensibility of the integument most acute?

34. Is the sensibility of the internal organs more or less acute than that of the skin?

35. What information do we acquire by means of the general sensibility?

36. What is the difference between general sensibility and sensibility to pain?

37. May general sensibility exist without sensibility to pain, and *vice versa?*

38. Why is the spinal cord a *nervous centre* as well as an organ of communication?

39. What is the *reflex action of the spinal cord?*

40. How is this reflex action seen in paralyzed persons?

41. How is the nervous stimulus conveyed in reflex action of the spinal cord?

42. Is this action accompanied by sensation? by consciousness? by volition? Why not?

43. Name instances of the involuntary reflex action of the spinal cord in health—in disease.

44. What is the effect of excessive irritability of the spinal cord in disease?

CHAPTER XIV.

THE CRANIAL NERVES.

Character of the Cranial Nerves.—Sensibility of the Face.—Fifth Pair of Cranial Nerves—its three Branches—their Distribution—their Sensibility.—Neuralgia.—Tic Douloureux.—Motor Branch of the Fifth Pair.—Muscles of Mastication.—Temporal.—Masseter.—Pterygoids.—Movements of Expression.—Facial Nerve—its Distribution—its Motive Power.—Paralysis of the Face.—Hypoglossal Nerve.—Movements of the Tongue.—Pneumogastric Nerve—its Origin and Distribution.—Pharyngeal Branch.—Act of Deglutition.—Sensibility of the Pharynx.—Protection of the Nostrils in Deglutition.—Laryngeal Branches of the Pneumogastric.—The Glottis—its Movements in Respiration.—Protection of the Glottis in Deglutition.—Formation of the Voice.—Action of the Larynx.

In the study of the spinal nerves we have seen that these nerves by their sensitive fibres supply sensibility to the skin of the body and limbs, and by their motor fibres communicate the power of motion to the corresponding parts.

141. **Functions of the Cranial Nerves.**—Now the same powers reside in the external portions of the head and face. The skin of these parts is also sensitive, and their movements are varied and important. Accordingly, they are supplied with nerves similar in many respects to those connected with the spinal cord. But as the nerves of the head and face pass directly from the brain through openings in the bony floor of the cranium, they are distinguished by the name of the *Cranial nerves.*

In all there are twelve pairs of cranial nerves. But

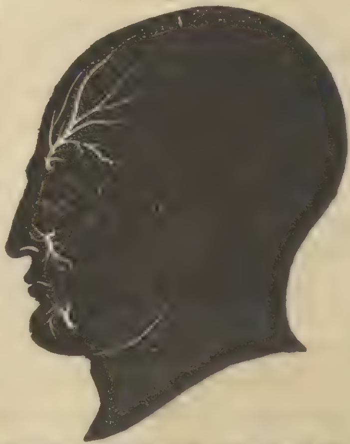
as some of these nerves are very peculiar in their nature, and have no relation with the external parts but only with the organs of the special senses, we shall examine for the present only those which are connected with the simpler and more ordinary nervous functions of this part of the body.

The first of these functions is that of *Sensibility*. This power is highly developed in all parts of the face, and at the tip of the tongue is more acute than in any other part of the body, being twice as great as in the ends of the fingers. The lips are also highly sensitive, and the eyelids, the nose, and the surface of the cheeks possess the same property in a somewhat less degree. The most insensible part of the head is that portion of the scalp which is covered with hair; but even here the surface is sufficiently sensitive to perceive readily the contact of foreign substances.

142. **Fifth Pair of Cranial Nerves.**—The sensibility of the face is supplied by a large and very interesting nerve, which is called the *Fifth pair*. Anatomists have given it this name because, in counting all the cranial nerves from before backward, it comes the fifth one in the series. It is also called the "trigeminal" nerve, because, after emerging from the base of the brain, and while still contained within the cavity of the skull, it divides into three great and nearly equal branches. Just at the level of this division the nerve has upon it a rounded swelling or ganglion of gray matter, which is called the "Gasserian ganglion," from the name of the anatomist who first described it. Its threefold branches then pass through three separate openings in the base of the skull, and, running thence from behind forward, are distributed to the skin of the three different regions

of the face. The first branch passes upward to the forehead and the top of the head, the second to the middle portion of the face, the nose, cheeks, and upper lip, and the third to the lower lip, the chin, and the adjacent parts. During their passage through the deeper textures, the second and third branches also send filaments respectively to all the teeth of the upper and lower jaw; and nervous fibres are also sent to the tongue and the inside of the mouth and nostrils (Fig. 48).

Fig. 48.



Distribution of the Fifth Pair upon the Face.—*a*. Gasserian ganglion; 1, 2, and 3. First, second, and third branches of the Fifth Pair.

Thus all the different parts of this region are supplied with sensibility. The fifth pair, therefore, is the great sensitive nerve of the face; and it is on account of the delicate organization and minute ramification of this nerve that the skin is here endowed with the sense of touch in such unusual perfection.

But when the fifth pair is exposed to irritation from disease, its sensibility is the source of exquisite pain. If a tooth, for example, be attacked by caries or decay of its hard substance, the suffering which it occasions is of extreme severity. For every tooth is provided with a filament coming from the fifth pair, which penetrates its root from below, and there lies concealed and defended by the hard covering of its crown. But when this

covering becomes wasted or destroyed from any cause, then the slightest touch of the food in mastication, or even the contact of the air, produces an irritation which penetrates to the nervous tissue below. Every one knows how intolerable is the pain of toothache from this cause. When the injury to the tooth is excessive, the only remedy is to extract it from its socket in the jaw. The nerve is then torn off at its root, and the sensibility of the tooth destroyed. Afterward the wounded tissues heal over, and the pain is permanently relieved.

The fifth pair is also the seat of an extremely painful affection termed *Neuralgia.* This is simply an irritation of the nerve from some disease of its tissue. All the sensitive nerves are liable to this affection; but when seated in the nerves of the face, it is so much more severe than elsewhere that it has received a distinct name, and is called "tic douloureux," or the "painful spasm;" because it seizes the patient in sudden twinges or paroxysms. The best protection against these troublesome affections is to preserve the general functions of the body in a sound and healthy condition.

143. **Motor portion of the Fifth Pair.**—But there is one part of the fifth pair which presents a remarkable difference from those which we have thus far examined. This is a portion of the third branch, which accompanies it through its opening in the skull, but which has a different destination and different properties. All the other parts of the fifth pair are sensitive in their character, and are distributed to the skin and lining membranes of the face. This portion, on the contrary, is motor in character, and is distributed to muscles. Moreover, it belongs to a set of muscles which are all associated in

one function, viz., that of mastication. The nervous branch which supplies these muscles with motive power is therefore called the *Masticator nerve.*

The muscles of mastication are four in number on each side. The two larger and more powerful are, 1st, the *Temporal*, and, 2d, the *Masseter* muscles.

The temporal muscle is so called because it is situated in the temples. Its fibres run upward from their attachment to the lower jaw, and are spread out in a fan-like form upon each side of the head in front of and above the ear. Place the fingers upon the temple, and then move the lower jaw upward and downward, and you will feel this muscle swelling and hardening at every alternate movement. It serves to press the lower jaw against the upper, and thus to bring the teeth firmly in contact with each other.

The masseter is a thick and strong muscle, situated at the back part of the side of the jaw. We can easily feel its movement in this situation during the process of mastication. Both these muscles act together, and in the same direction; and they accordingly move the lower jaw from below upward with great rapidity and force.

But, during mastication, the lower jaw is also moved from side to side, in order to produce the grinding action which is so essential for the comminution of the food. This lateral movement is performed by two internal muscles on each side, called the *Pterygoid* muscles, which are concealed between the inner part of the jaw and the base of the skull. They are rather smaller than the others, but share with them the work of moving the jaw in mastication.

All these muscles are exclusively animated by the

motor branch of the Fifth pair. This branch is therefore justly named the masticator nerve.

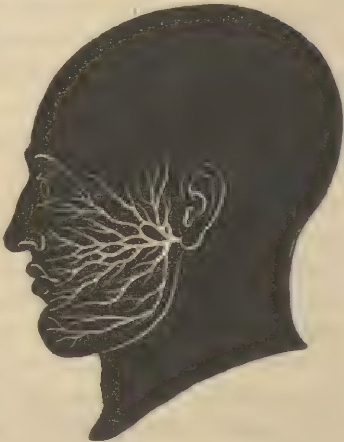
144. **Seventh Pair, or Facial Nerve.**—But, beside the acts concerned in mastication, the face itself has very numerous and important movements. Its whole surface is endowed with a mobility by which its expression is constantly changed, and the varying emotions of the mind portrayed upon its exterior. The eyelids may be opened or closed; the nostrils expanded or contracted; the lips drawn upward or downward, and their opening enlarged or narrowed. These movements may also be combined with each other in a multitude of various ways, so as to change in a corresponding degree the external appearance and configuration of the face. They are therefore called the *Movements of Expression.* By their aid the face speaks a language of its own, and a language which is easily understood, for every one comprehends its meaning by instinct.

The muscles of expression are animated by a nerve which is called the *Facial nerve.*

The facial nerve originates from the side of the medulla oblongata, and, after passing through a long and tortuous canal in the floor of the skull, emerges from a small orifice in the bone a little behind the external opening of the ear. It then curves forward beneath the ear, passes by several branches through the substance of the parotid gland which occupies this situation, and then, spreading out in various directions, is distributed to the muscles which move the different parts of the face (Fig. 49).

The natural function of this nerve has already been explained. It is the nerve of expression, and enables the countenance to assume those varied appear-

Fig. 49.



The Facial Nerve.

ances which indicate the changes of mental emotion. Like the fifth pair, however, it is also subject to disease; and, when affected in this way, its natural function is consequently disturbed. As irritation of the fifth pair produces pain, so irritation of the facial nerve produces convulsive twitchings of the face, and an unnatural change in its expression. The facial nerve may also be injured, either by accidental violence or by swellings pressing upon it in its bony canal. The result of this injury is a singular kind of paralysis, known as "paralysis of the face." This is almost always confined to one side; but on this side the face becomes devoid of animation, and remains passive and motionless. The feelings have no longer any influence upon its action, and the features cease to exhibit their natural changes of expression.

145. **Motor Nerves of the Eyeball.**—Beside the facial, there are three small motor nerves belonging to the cranium which do not appear externally, but go to animate the muscles of the eyeball, within the orbit of the eye. They are the third, fourth, and sixth pairs of cranial nerves. They provide for the movement of the eyes from right to left, or upward and downward, or for turning obliquely in their orbits. They assist in

this way, to a certain extent, in the expression of the face.

146. **Motor Nerve of the Tongue.**—There is still another motor nerve which is distributed to the muscles of the *tongue.* It is therefore called the "hypoglossal nerve." It comes from the front part and side of the medulla oblongata, passes through an opening in the adjacent portion of the skull, and then runs forward, deeply concealed among the tissues of the neck, until it arrives beneath the tongue. It then passes upward into the substance of the organ, sending out branches and ramifications to all the muscular bundles of which its mass is composed. It provides for all the varied movements which the tongue is required to perform, both in breaking and in the mastication of the food.

The tongue, accordingly, like the other parts about the face, is supplied with a *sensitive* nerve and a *motor* nerve. Its sensitive nerve is the branch which it receives from the fifth pair; and its motor nerve is the hypoglossal, which is distributed to its muscular fibres.

But there are other nerves coming from the brain beside those which are devoted to sensation and voluntary motion. The most remarkable of these is a long and very important nerve, termed the *Pneumogastric.*

147. **Pneumogastric Nerve.**—The pneumogastric nerve is so called because its final branches are distributed to the lungs and to the stomach. To reach these organs, however, it traverses a long distance from its origin at the base of the brain, and passes successively through the neck, the chest, and the upper part of the abdomen. On account of this extended and varied course, so different from that of the other cranial nerves, the older

anatomists called it the *Par vagum*, or the "wandering pair." The name was well deserved.

The pneumogastric takes its origin from the side of the medulla oblongata, by ten or fifteen separate filaments, which soon unite into a single nervous cord, and pass, in this form, through a bony canal in the floor of the skull. It has an abundance of sensitive fibres of its own, and receives, beside, motor fibres by branches which join it from the facial nerve, the hypoglossal nerve, and others in its neighborhood. At a short distance from its origin it has also a small swelling or ganglion, like the Gasserian ganglion of the fifth pair. After emerging from the skull, it pursues its course downward through the neck, deeply imbedded in the tissues, and in close company with the great blood-vessels of the part, and thus enters the cavity of the chest. During this passage it gives off three important branches.

The first of these is the *Pharyngeal* branch.

As its name implies, this nerve is distributed to the "pharynx," or the funnel-shaped muscular tube which receives the food from the back part of the mouth and conducts it to the œsophagus. The fibres of the nerve penetrate its muscular layers and lining membrane, and supply them both with sensibility and motive power.

The second is the *Superior laryngeal* branch. This is distributed to the lining membrane of the larynx, and communicates to it, as we shall hereafter see, a sensibility of an important character.

The third branch follows a remarkable course. It is given off from the main trunk of the nerve in the lower part of the neck or just at its entrance into the chest. It then, after continuing a very short distance down-

ward, returns upon itself, and, curving round the great vessels at the top of the chest, mounts upward again along the neck until it arrives at the level of the larynx, when it is distributed to the various muscles of this organ. It is therefore called the *Inferior laryngeal* branch.

This nerve has a singular historical interest; for it was especially studied by Galen, the most eminent physician of the Roman Empire in the second century, who examined its properties, and discovered its physiological connection with the function of the voice. He called it the "recurrent" nerve, owing to its peculiar course in returning, as we have described, from below upward. It still retains this name, by which it is often designated at the present day.

Thus the larynx is supplied with two separate nerves, both branches of the pneumogastric, viz., the superior laryngeal, which gives sensibility to its lining membrane, and the inferior laryngeal, which communicates to its muscles the power of motion.

Fig. 50.

Diagram of the Pneumogastric Nerve, with its principal branches.—1. Pharyngeal branch; 2. Superior laryngeal; 3. Inferior laryngeal; 4. Branches to the lungs; 5. Stomach; 6. Liver.

The inferior laryngeal branch also gives filaments to the œsophagus in the region of the neck.

The pneumogastric nerve, in its passage through the chest, sends off numerous filaments, which penetrate the lungs, and follow the ramification of the bronchial tubes to their termination in the air vesicles. To these organs it communicates a peculiar sensibility, the importance of which we shall learn hereafter. It then enters the abdomen, and is there finally distributed to the walls of the stomach (Fig. 50).

The upper branches of the pneumogastric nerve are connected with the mechanism of two most important functions, viz., that of *Swallowing* and that of *Respiration.*

148. **Action of the Pneumogastric Nerve in Swallowing.** —As we have already seen, both the lining membrane of the mouth and the surface of the tongue are endowed with ordinary sensibility of a high degree by the fibres of the fifth pair. But as the food passes toward the back part of the throat and into the pharynx, it meets with another sensibility of a peculiar kind. This sensibility no longer gives rise to the sensations of ordinary touch, but it excites at once, by a reflex action, the whole muscular apparatus of deglutition. Of these muscles the three most active are those which are called the *Constrictors of the pharynx*, because they are wrapped round this canal in such a way as to constrict or compress it successively from above downward, and thus to carry the food through it in the same direction.

This reflex action takes place through the pharyngeal branch of the pneumogastric nerve; its sensitive fibres receive the impression of the food, and its motor fibres excite the muscles to contraction.

It is for this reason that the action of the pharynx in swallowing is involuntary. So long as mastication is going on, we can vary or arrest its movements at will; but when once the food has passed the isthmus of the throat, and is fairly within the grasp of the pharynx, these muscles close upon it by reflex action, and carry it with a kind of spasmodic movement downward to the œsophagus.

But when foreign substances not fit for deglutition are brought in contact with the lining membrane of the pharynx, the opposite effect is produced. If the feather of a quill or the ends of the fingers be thrust backward into the throat, the impression so produced upon its lining membrane no longer excites the movement of swallowing, but a resistance and reaction of the muscles of the pharynx; and if the irritation be continued, the œsophagus and stomach at last sympathize with the reaction, and may even be excited to vomiting. Thus all the reflex actions are so arranged that they provide for the natural and regular operation of the animal functions. When the proper stimulus of the lining membrane is presented to it, the nervous system responds by an easy and natural movement; but it revolts against an unnatural stimulus, and rejects the offending substance by a spasmodic effort of the muscles.

149. **Protection of the Nostrils during Deglutition.**—There is still another point in the mechanism of deglutition which requires attention.

If you look into the back part of the throat when it is illuminated by the sunshine or a strong gas-light, you will see that the cavity of the mouth is partially separated from the pharynx by a sort of muscular cur-

tain or partition hanging downward from above, and attached on each side by double folds of the lining membrane. This is the *Hanging Palate.* Beneath it is the arched passage or doorway which leads from the mouth into the pharynx, and from the middle of the arch hangs a soft conical fleshy appendage called the "uvula."

Now behind this hanging curtain of the palate the upper part of the pharynx communicates with the nostrils, and it is through this passage that the air enters in respiration when the mouth is closed. When we inhale any pungent odors by the nostrils, we often feel them penetrate into the back of the throat by passing in this way with the inspired air through the posterior part of the nostrils and behind the hanging palate.

Accordingly, when the food is carried backward from the mouth to the pharynx, it would escape upward into the passage of the nostrils if there were not some provision to prevent it.

But at the moment of deglutition the muscles on the two sides of the palate contract and draw together the arched sides of the passage, as the two halves of a curtain might be drawn together to close the opening of a window. At the same time, the palate itself is stretched backward like an awning, and shuts off in this way the communication between the pharynx below and the nostrils above; and the food, urged by the tongue from the mouth into the pharynx, and finding no passage open into the nostrils, necessarily turns downward, and is carried into the œsophagus.

All these movements are excited at the same time by the reflex action of swallowing.

Secondly, the laryngeal branches of the pneumogas-

tric nerve play a very important part in the act of respiration.

150. **Structure of the Glottis and its Movements in Respiration.**—The larynx, which is the commencement of the trachea and bronchial tubes, communicates with the front part of the pharynx by a narrow opening or crevice, which we have already spoken of as the "glottis." Accordingly, the air, in respiration, enters by the mouth and nostrils into the back part of the throat, and thence passes into the larynx by the opening of the glottis.

The structure of the glottis is as follows: The larynx, as we have already seen, is a kind of cartilaginous box, formed of various pieces connected with each other by articulations and ligaments. Its internal cavity is, for the most part, as spacious as that of the trachea; but just at its upper portion it is partly obstructed by two elastic bands of fibrous tissue, which are termed the *Vocal chords.*

We shall hereafter see how important a function these chords perform in the production of the voice, from which their name is derived. The vocal chords are attached, side by side, at the front of the larynx, and thence run backward nearly parallel with each other, thus leaving between them a narrow fissure, which is the opening of the glottis. All the space outside the vocal chords is filled up by the lining membrane and muscles of the larynx. If you were to stretch two cords over the mouth of an empty barrel, and then lay a folded cloth on each side between the cord and its edge, you would have a tolerably correct idea of the anatomical arrangement of the larynx. The barrel would represent the larynx itself, the space between the two cords would be the glottis, and the folded

cloth would occupy the situation of the lining membrane and the muscles on each side.

Now the opening of the glottis is too narrow to admit the air in sufficient quantity to the lungs, since its capacity is only about one third as great as that of the trachea. How is it, therefore, that the lungs are filled through this constricted passage?

It is because the larynx is movable and takes part in the acts of respiration. Every time the chest expands to inhale the air, the glottis opens to admit it; and a series of alternate movements of expansion and collapse are thus performed by the glottis simultaneously with those of the chest and abdomen. They are accomplished in this way.

At their posterior extremity the vocal chords are attached to two small triangular cartilages, which are connected with the rest of the larynx by an articulation or joint at their inner angle. These are called the *Arytenoid cartilages.* Their muscles are so arranged that they may be turned or rotated upon their articulations, so as to move the vocal chords outward and thus separate them from each other. Very much in the same way a bell-cord is sometimes attached to the wire by a triangular brass plate, which turns upon a hinge at one corner; and when the cord is pulled downward the brass plate rotates upon its hinge, and draws the wire with it in the same direction. Accordingly, when both the arytenoid cartilages move at the same time, the vocal chords are stretched and separated from each other, and the opening of the glottis between them is widened to admit the passage of the air.

The movements thus performed are called the *Respiratory Movements of the glottis.* They are depend-

Fig. 51.

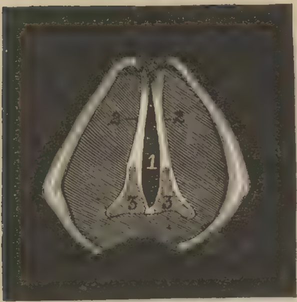


Fig. 51. Larynx viewed from above, with glottis narrowed.

Fig. 52.

Fig. 52. Same, with glottis opened: 1. Orifice of glottis; 2, 2. Vocal chords; 3, 3. Arytenoid cartilages.

ent upon the inferior laryngeal branch of the pneumogastric nerve, which animates the muscles of this part.

But, beside its power of motion, the glottis is endowed with an exquisite and peculiar sensibility, which is essential to the safety of life.

So long as it is only air which enters the larynx, the natural movements of the part are performed with ease and regularity. But if any foreign substance, such as a crumb of bread or a drop of water, happen to get between the vocal chords and seek to gain entrance into the trachea, the lining membrane of the larynx at once feels an irritation which excites all the muscles in its neighborhood to an active and determined resistance. They close the orifice of the glottis with a convulsive movement, and the foreign substance is at last expelled by the spasmodic efforts of coughing. This peculiar sensibility of the larynx is dependent upon the superior laryngeal branch of the pneumogastric nerve, distributed to its lining membrane.

This nerve, accordingly, is the safeguard of the glottis. It stands like a sentinel at the entrance of the air

passages, to give notice of the intrusion of any foreign substance into the lungs, and thus protect them against injury from without.

Another very important point in the history of the larynx is its connection with the act of swallowing.

151. **Protection of the Glottis during Deglutition.**—As we have seen, the glottis communicates with the pharynx. But it is through this passage that all the food passes downward to the stomach. How is it, therefore, that it does not fall into the larynx, and thus produce strangulation every time the act of swallowing is performed?

First of all, it is because, at the instant the food is about to be swallowed, respiration stops. There are various nervous actions in the body which are said to be "incompatible" with each other; that is, they can not be performed at the same time. Thus we can move the two hands over and over in a circle from behind forward, in front of the body, either alternately or together; but we can not move one of them from behind forward and the other from before backward at the same time. Some inexplicable interference of the nervous system prevents it; so that, though the two movements may easily be performed separately, it is impossible to perform them together. In the same way we can turn the two eyes to the right or the left together, but we can not turn one of them to the right and the other to the left at the same time.

Now there is a similar nervous incompatibility between the acts of swallowing and inspiration. It is a necessary preliminary to the deglutition of the food that respiration be suspended. The consequence is, that the glottis is not opened as usual, but remains a narrow

chink, offering but little opportunity for the entrance of the food.

Nevertheless, this accident sometimes happens, and every one knows the distress which is occasioned by even the smallest particle of food getting entangled in this way in the larynx. Whenever it occurs, we shall always find that the difficulty is caused in the same way, namely, *by a sudden inspiration taken at the moment when the food is being swallowed.* We can not take such an inspiration voluntarily; but it is sometimes produced by a sudden impression upon the senses, as of an unexpected sight or exclamation, or excitement of any kind. The nervous system is then, as it were, taken by surprise; its natural operation is disturbed, and a quick inspiration opens the glottis and sucks the food, with the air together, into the cavity of the larynx.

It is evident, therefore, how carefully all sources of hurry or disturbance should be avoided during the mastication and swallowing of the food. The meals should be taken quietly, and no sudden interruptions of an exciting nature be allowed while they are going on. With children especially, where the nervous system is highly impressible, these precautions should be constantly observed; for such an accident is always alarming, and may easily be fatal in its results.

But the protection of the glottis in deglutition is also provided for by Nature in other ways.

If we place the finger upon the larynx in front of the throat, and then go through with the movements of swallowing, we shall find that at the instant of deglutition the larynx is drawn rapidly upward beneath the base of the tongue. As the base of the tongue is at the same moment thrust backward, it tends to cover the

opening of the glottis, and still farther to obstruct its entrance. Furthermore, the lower constrictor muscles of the pharynx are themselves attached on each side to the lateral portions of the larynx, and from this situation they encircle the pharynx behind. Now it is these muscles which act in deglutition; and at the same moment that they compress the pharynx they necessarily draw also by their attachments upon the larynx, press its two sides more closely together, and thus shut up completely the orifice of the glottis. By the combined operation, accordingly, of these various movements, the glottis, which is opened in inspiration to admit the air, is securely closed in deglutition during the passage of the food.

152. **Production of Vocal Sounds in the Larynx.**—The last function of the larynx is the *formation of the Voice.*

For the larynx is a musical instrument. It is here that all the vocal sounds are produced, and modulated from the higher notes to the lower, with all the alterations of tone that give variety and expression to the voice. These sounds are divided into vowels, consonants, and words by the motions of the lips and tongue; but the voice itself is formed in the larynx by the action of the vocal chords.

Sound is caused by a vibration; and any body which is capable of vibrating will produce a sonorous effect. Thus a violin-string, when snapped by the fingers or set in motion by the bow, gives out a note which is higher or lower according to the rapidity of its vibration. To do this, however, it must be *tense and elastic.* If it be loose and flexible it is incapable of vibrating, and consequently can not produce a sound. The same string also will give out a deep sound when it is moderately

tight, and a more acute one when it is stretched to a high degree of tension. In a flute or a trumpet, the air itself, which is always elastic, is thrown into vibration; and the sound which is produced varies with the width of the opening and the length of the column of air contained in the instrument. In an organ-pipe the reeds are first made to vibrate, and they then set in motion the column of air above them. The long and wide tubes thus give a deep sound, the short and narrow tubes an acute one.

The formation of the voice in the larynx is somewhat similar. The first peculiarity to be noticed is that *the voice is formed during expiration and not during inspiration.* We always speak while the air is passing out through the larynx, and never while it is passing inward to the lungs. We drive the air forcibly through the larynx to produce a sound, just as we blow it through a horn or an organ-pipe for the same purpose.

Secondly, when the voice is to be sounded, *the vocal chords are drawn together and tightly stretched.* In order to produce the necessary vibration, the orifice of the glottis must be narrowed, and the vocal chords thrown into a state of tension which will enable them to move rapidly like the strings or reeds of a musical instrument. Then the column of air passing between them is itself thrown into vibration, and thus produces the vocal sound. The note sounded by the voice will therefore be high or low, acute or grave, as the vocal chords are more or less tightly stretched, and as the orifice of the glottis is narrower or wider. In sounding a low note, the glottis is left comparatively open, and the vocal chords are loose; in a high note, the vocal chords are tightened and brought nearer together, so as to

diminish the orifice of the glottis to its narrowest dimensions.

Finally, the larynx is raised and lowered during the formation of different sounds. If we place the finger upon this part, we shall find that when the lower notes are sounded it is drawn down toward the chest, while during the formation of acute sounds it is carried forcibly upward. Thus the two columns of air above and below the glottis, in the trachea and in the pharynx, are lengthened or shortened, and widened or narrowed, as the sounds emitted by the larynx vary in character and tone.

All the movements of the glottis in the formation of the voice, as well as those connected with respiration, depend upon the inferior laryngeal branch of the pneumogastric nerve.

153. **Distribution of the Pneumogastric to the Lungs.** —The lower portion of the pneumogastric nerve also sends branches to the *lungs*. These branches form a plexus or network at the back part of the lungs by dividing and again inosculating with each other, and from this plexus their filaments penetrate into the tissue of the organs, following the successive divisions of the bronchi and bronchial tubes (Fig. 50). They are distributed to the lining membrane of the bronchial tubes and the pulmonary lobules, and communicate to these parts a peculiar sensibility by which they are enabled to perceive the condition of the air contained in the air vesicles and of the blood contained in the capillary blood-vessels. Accordingly, when the air becomes contaminated, these filaments receive the impression of its impurity. The pneumogastric nerve thus presides over the condition of the air passages throughout their

course, from the opening of the glottis to the termination of the pulmonary vesicles.

154. **Distribution of the Pneumogastric to the Stomach.** —Finally, the last branches of the pneumogastric nerve are distributed to the stomach. Here, as elsewhere, the nerve contains both sensitive and motor fibres. The sensitive fibres are distributed to the lining membrane of the stomach, the motor fibres to its muscular coat. Here there is also a peculiar sensibility, followed by a reflex action. For the lining membrane of the stomach is not endowed with ordinary sensibility. It does not feel the contact of the food as we could feel it with the fingers or the lips. But we know that when the food passes into the stomach, its presence excites the "peristaltic action" of the muscular coat, by which it is moved constantly from side to side, mingled thoroughly with the gastric juice, and finally carried onward through the pylorus into the intestine. This important movement is entirely involuntary, and is performed usually even without our knowledge. It is a reflex action, excited by the peculiar sensibility of the lining membrane of the stomach, through the sensitive fibres of the pneumogastric nerve, and conveyed by its motor fibres to the muscular coat of that organ.

The pneumogastric nerve, accordingly, controls the condition and actions of the upper part of the alimentary canal, from its commencement in the pharynx to the pyloric extremity of the stomach.

Thus the cranial nerves, by their motor and sensitive filaments, preside over the sensibility and movements of the face, the functions of mastication and deglutition, the peristaltic movements of the stomach, the respiratory and vocal movements of the glottis, and the

whole extent of the air passages throughout the lungs.

QUESTIONS FOR CHAPTER XIV.

1. What are the *cranial nerves?*

2. How many pairs are there of cranial nerves?

3. What nervous function is highly developed in the skin of the face?

4. At what part is sensibility more acute than elsewhere?

5. By what nerve is the face supplied with sensibility?

6. Why is it called the "*fifth pair?*"

7. Why is it called the *trigeminal* nerve?

8. What is the *Gasserian ganglion*, and where situated?

9. How are the three great branches of the fifth pair distributed?

10. What effect is produced by any irritation of the fifth pair?

11. What is the cause of *toothache?* and in what nerve is the pain situated?

12. What becomes of the nerve when the tooth is extracted?

13. What is *neuralgia?*

14. What name is given to neuralgia of the face? Why?

15. Which branch of the fifth pair is accompanied by *motor* fila ments?

16. What name is given to the nerve containing these filaments?

17. Why is it called the *masticator* nerve?

18. What are the muscles of mastication?

19. What is the situation of the *temporal* muscle?

20. What is the direction of its fibres?

21. What is the action of this muscle upon the lower jaw?

22. Where is the *masseter* muscle situated?

23. What is its action on the lower jaw?

24. What other muscles take part in the movements of mastica tion?

25. Where are the pterygoid muscles situated?

26. What movements of the jaw are produced by them?

27. What other movements are performed by the face?

28. By what nerve are the muscles of expression animated?

29. Where does the facial nerve originate?

30. Where does it pass through the floor of the skull?

31. What is its subsequent course and distribution?

32. Is the facial nerve a *sensitive* or a *motor* nerve?

33. What effect is produced on the face by injury or disease of the facial nerve?

34. What nerves provide for the movements of the eyeball?

35. What nerve supplies the muscles of the tongue?

36. What is the pneumogastric nerve, and what is its final distribution?

37. What other name is given to this nerve, and why?

38. Where does the pneumogastric nerve originate?

39. Does it contain sensitive or motor fibres, or both?

40. Whence does it derive its motor fibres?

41. In what direction does it pass after emerging from the cavity of the skull?

42. What is the first branch of the pneumogastric nerve?

43. To what organ is the pharyngeal branch distributed?

44. What properties does it communicate to the pharynx?

45. What two branches are distributed to the *larynx?*

46. What is the peculiarity in the course of the *inferior laryngeal* branch?

47. What name was given to this nerve by Galen?

48. What property is communicated to the larynx by the *superior laryngeal* nerve? by the inferior laryngeal nerve?

49. To what other organs are the branches of the pneumogastric distributed?

50. With what two important functions are the upper branches of the pneumogastric nerve connected?

51. Does the pharynx possess ordinary sensibility?

52. What reflex action is produced by the sensibility of the pharynx?

53. What name is given to the muscles of the pharynx? and why?

54. By what nerve are they excited to act when food enters the pharynx?

55. Is the action of the pharynx in swallowing voluntary or involuntary?

56. What effect is produced by irritation of the pharynx with foreign substances?

57. What is the *hanging palate?* What is the *uvula?*

58. What open passage is there behind the hanging palate?

59. How is the food, in swallowing, prevented from escaping into the back part of the nostrils?

60. Where does the larynx communicate with the pharynx?

61. What are the *vocal chords?* and where are they attached?

62. What is the opening left between them?

63. What is the size of the opening of the glottis compared with that of the trachea?

64. What movement takes place in the glottis at the time of inspiration?

65. To what are the posterior ends of the vocal chords attached?

66. In what direction can the arytenoid cartilages move?

67. What effect has this motion on the vocal chords and the opening of the glottis?

68. What is the object of the opening of the glottis in inspiration?

69. What name is given to these movements of the glottis?

70. What is the peculiarity in the *sensibility* of the glottis?

71. What effect is produced by its irritation with a foreign substance?

72. What protective action does the superior laryngeal nerve exert over the air passages and lungs?

73. How is the food prevented from passing into the larynx in swallowing?

74. Why can we not swallow at the moment of inspiration?

75. Mention other examples of "incompatible" movements.

76. How is it that particles of food sometimes fall into the larynx in swallowing?

77. What precautions should be taken to prevent this accident?

78. How does the action of the *constrictors of the pharynx* serve to prevent the food passing into the larynx?

79. What other function is performed by the larynx?

80. How is sound produced? what gives the vibration in stringed instruments?

81. What must be the condition of a cord in order that it may vibrate so as to produce a sound?

82. When does the same cord give an acute sound, and when a deep sound?

83. What gives the vibration in wind instruments?

84. What tubes give an acute sound, and what a deep sound?

85. Is the voice produced in inspiration or in expiration?

86. What is the condition of the vocal chords when the voice is sounded?

87. What is their condition in sounding a *high* note?

88. What in sounding a *low* note?

89. Upon what nerve do the vocal movements of the glottis depend?

90. What is the distribution of the pneumogastric nerve in the *lungs?*

91. What kind of sensibility does it communicate to the lungs?

92. To what organ are the last branches of the pneumogastric nerve distributed?

93. To what part of the stomach are its *sensitive* fibres distributed?

94. To what part are its *motor* fibres distributed?

95. What reflex action of the stomach takes place through the pneumogastric nerve?

96. Name the various functions presided over by all the cranial nerves.

Dec

CHAPTER XV.

THE BRAIN.

Form of the Brain—its Anatomical Divisions.—Medulla Oblongata.—Cerebellum.—Pons Varolii.—Tuber Annulare.—Cerebrum.—Functions of the Cerebrum.—Memory.—Judgment.—Reason.—Effects of Injury to the Cerebrum.—Functions of the Tuber Annulare.—Sensation and Volition.—Instinctive Movements.—Functions of the Medulla Oblongata.—Movements of Respiration—how performed.—Reflex Action of Medulla Oblongata.—Effects of Injury to Medulla Oblongata.—Different kinds of Reflex Action in the Brain.

155. THE **Brain** is the great mass of nervous substance which occupies the cavity of the skull. It is composed of various collections of gray matter, or ganglia, which are united with each other and with the spinal cord by numerous bundles of white nervous fibres.

The brain, like the spinal cord, is double. It is formed of two great lateral masses which lie side by side in the skull, separated in front and above by a deep furrow or fissure, but connected beneath by the continuation of the nervous substance. It is also separated by transverse furrows, and by certain differences in structure, into three principal divisions, varying in size, appearance, and situation. These are the *Cerebrum*, the *Cerebellum*, and the *Medulla oblongata*.

156. **Medulla Oblongata.**—When the spinal cord enters the cavity of the cranium by the great foramen situated at the base of the skull, it expands, as we have

mentioned in a previous chapter, into a widened oblong mass, which still preserves the general external appearance of the spinal cord. This is the *Medulla oblongata*. Its increased width is partly owing to its fibres beginning at this point to turn and wind obliquely in various directions, but also to the fact that an important mass of gray matter is here buried in its substance, known as the "ganglion of the medulla oblongata." Nearly all the cranial nerves also take their origin from this part, or its immediate neighborhood, and their fibres accordingly are added to those derived from the spinal cord. Like the spinal cord, therefore, the medulla oblongata consists of a collection of gray matter, covered and concealed by the white fibres upon its outer surface.

157. **Cerebellum.**—Above and behind the medulla oblongata is the *Cerebellum*. This is a much larger nervous mass, and is instantly distinguished from those which have preceded by its peculiar appearance and structure. Its outside is composed, not of white, but of gray nervous matter, and this nervous matter is arranged in abundant narrow laminæ or convolutions, for the most part running transversely, and closely packed, like a gray cloth or shawl folded in many layers. In its interior, on the contrary, the cerebellum is composed of white substance. The columns of the spinal cord, while passing through the medulla oblongata, give off some of their fibres; and these fibres, turning obliquely upward and backward, spread themselves out in the thickness of the cerebellum, and finally come into connection with the gray matter upon its surface.

Beside this, the two lateral halves of the cerebellum are connected with each other in a remarkable way.

From the whole inner surface of its gray matter there start on each side a multitude of white nervous filaments, which pass downward and forward toward its centre, gradually approaching each other, and uniting into a flattened bundle of parallel fibres. This ribbon-shaped bundle then emerges from the lower and front part of the cerebellum, curves round the base of the brain just in front of the medulla oblongata, and then returns upon the opposite side to spread out again in the substance of the other half of the cerebellum.

Thus this mass of nervous fibres, spread out at their two extremities, but united into a parallel band at their middle, form a transverse communication between the right and left sides of the cerebellum.

In its middle portion, where it encircles the base of the brain in an arched form, it is called the "Pons Varolii," or the "Bridge of Varolius," because the fibres of the medulla oblongata, in continuing their course, pass underneath it, like a river under a bridge.

158. **Tuber Annulare.**—Now where the fibres of the medulla oblongata pass under the pons Varolii, another deposit of gray matter is found in the interior of the mass. This collection of gray matter within, together with the prominence of the pons Varolii on the outside, gives to this part of the brain the appearance of a circular or ring-like protuberance. It is therefore known by the name of the *Tuber annulare;* and the gray matter in its centre is called the "ganglion of the tuber annulare."

Beyond and in front of the tuber annulare the fibres coming from the spinal cord and medulla oblongata pass upward and onward in two great rounded bundles, which are called the "peduncles of the brain."

They have received this name because the two halves of the brain are supported upon these peduncles, like a flower upon its stem. Their fibres, running continually upward, immediately after they have passed the level of the cerebellum spread out in a fan-like form, in front and behind, to the right and the left, and thus finally terminate in the gray substance of the cerebrum.

159. **Cerebrum.**—The cerebrum is by far the largest of all the nervous masses contained within the skull. It overlaps all the remaining parts, in front, above, and behind, so that they are covered by it as if with a kind of vaulted roof or dome. The outer and upper part of this dome is formed of gray matter, folded and convoluted in innumerable directions; its interior is formed mostly of white substance, viz., the fibres which, as we have already seen, pass upward from below, and thus connect this principal part of the brain with the medulla and spinal cord. The two halves of the cerebrum are also connected, like those of the cerebellum, by a great bundle of transverse fibres, converging from the gray matter and passing from side to side; only this transverse band does not emerge from the brain, like the pons Varolii, but remains concealed and imbedded in its substance.

At the base of the cerebrum, on each side, there are also two other deposits of gray matter, one in front and one behind, called respectively the "striated bodies" and the "optic thalami." These ganglia form a part of the substance of the cerebrum, and stand, as it were, at its entrance or gateway, through which the fibres from below pass upward to its surface (Fig. 53). In the substance of the cerebrum also, beneath the folded cover-

Fig. 53.

Diagram of Human Brain, in vertical section, showing the situation of the different ganglia and the course of the fibres.—1. Ganglion of the sense of smell; 2. Cerebrum; 3. Corpus striatum; 4. Optic thalamus; 5. Ganglion of the sense of sight; 6. Cerebellum; 7. Ganglion of the tuber annulare; 8. Ganglion of the medulla oblongata.

ing of its gray matter, there are pillars, and vaults, and curtains, and galleries, and passage-ways, and many varied details of anatomical structure, too complicated for minute description. Many of these anatomical parts have uses which are still unknown to us; but we are acquainted with the structure and functions of the principal mass and its connection with the other portions of the brain.

160. **Functions of the Cerebrum.**—The cerebrum is the organ of the mind. By that we mean that it is this division of the nervous system through which the intellectual powers communicate with the body. Reason, judgment, memory are the mental faculties whose operation is connected with the function of the cerebrum. We know this because, when this part of the brain is injured, it is these faculties which are impaired, and when it is deficient they are absent to a corresponding degree. What is the nature of these faculties, and

how do they manifest themselves through the action of the brain?

The simplest and most fundamental of these powers is that of *Memory*. This faculty lies at the basis of all mental improvement, and even the simplest intellectual operation would be impossible without it. By it alone we are enabled to retain the names of things and the meaning of words, so that we can write and speak. Nearly all our actions are guided by what has taken place before, and therefore, if we had no memory, most of our acts would be capricious and unreasonable. A deficiency of memory is the earliest indication of idiocy in children, and it is on account of the want of this faculty that such children can not learn to read, and in many cases can not even talk. A deficiency of memory is also the most unfailing consequence of injury to this part of the brain. When an attack of apoplexy is coming on, an unusual forgetfulness is among the first symptoms which are manifested; and in more permanent affections of the brain it gradually increases, until the power of recollecting even the days of the week or the events of the day is permanently lost.

The next important intellectual faculty is *Judgment*. By this is meant the power of appreciating the true importance of things, and the relations of cause and effect. A person who is deficient in this respect is liable to pay too much attention to things which are of little consequence, and to neglect those which are really important. He is also unable to perceive that what happens at one time is caused by something else which has preceded. He knows only that the two events have happened, but he does not see what is the connection between them. Accordingly, it is of no use to punish

an idiot, because he does not understand that the punishment is a consequence of what he has done before.

Finally, *Reason* is the faculty by which we compare the causes and consequences of things in such a way as to guide our actions. We can thus use the information acquired by memory and judgment to avoid difficulties and obtain success. An unreasonable person, therefore, is one who does not use the proper means to accomplish his purposes. This is characteristic of idiocy and of some kinds of insanity.

All these mental faculties are liable to be developed, to a greater or less degree, in different persons, or even in the same person, at different ages. Like the sensibility of the skin, they are sometimes acute and sometimes feeble. They are always diminished when the cerebrum is injured, even though the other functions of the nervous system may remain entire.

Now all acts which are of an intelligent nature require this operation of the mind; the simplest, as well as the most profound and complicated. For instance, we feel that the air of a room is cold, and we accordingly shut the window. This is a reflex action of the nervous system. The beginning of it is the sensation of cold; the end is the voluntary act of closing the window. But between the two there is an intellectual operation, by which we understand the cause of our sensation, and how we may remove it by the voluntary act. This mental process is especially connected with the function of the cerebrum.

160. **Functions of the Tuber Annulare.** — The next function of the nervous centres which we shall study is the double function of *Sensation and Volition.* We have already spoken of these faculties in connection

with the sensibility and power of motion in the spinal nerves. But we have found that these organs only serve as conductors, and that the real functions have their seat in the interior of the brain.

These faculties, however, are not situated in the cerebrum. The substance of the cerebrum is not even sensitive; and, provided no other parts of the brain be injured, it may be cut or lacerated in any way without producing pain, as has often happened in accidents and surgical operations. Physiologists have seen reason to believe that the powers of sensation and volition are located farther down, in the gray matter of the *Tuber annulare.* What is the nature of these functions, and how are they connected with each other?

A complete sensation is always accompanied by consciousness. This is very different from the mere nervous impression received by a sensitive nerve. For the nerve itself does not feel, it only conducts the impression; and the sensation is not perceived until it arrives at the brain, where consciousness resides. It is the ganglion of the tuber annulare which thus receives the impression conveyed by the nerve, and instantly converts it into a conscious sensation.

This ganglion is also the seat of volition. By this term we understand that nervous action by which we command the muscles through the influence of the will. This command is transmitted by the nerves, but its origin is in the brain.

Now volition is entirely distinct from reason. The intention or desire to perform an act is a different thing from its positive execution. Even when we have already determined to raise the arm or to advance a step, there still remains a nervous process by which the mus-

cles are actually set in motion. This process is the act of volition, and any movement so performed is called a "voluntary" movement.

But there are some voluntary acts which are performed independently of the mind. They have nothing to do with memory or judgment, and are executed instantly whenever we receive a particular sensation. This is the nature of all those acts which are performed *by instinct*. Thus the sight of a threatening object inspires terror, and we immediately endeavor to escape or defend ourselves from it. The sense of hunger leads us to take food; but this is simply because we desire it, and not because we reflect that it will nourish the body by the process of digestion, still less because we remember how this process is accomplished. All the actions of this kind are voluntary, but they do not result from any reasoning power which precedes them. They are guided by a blind impulse, in which we recognize only the sensations which we receive and the desires which they excite. These instinctive and voluntary movements are performed by the reflex action of the tuber annulare.

161. **Function of the Medulla Oblongata.**—There is another reflex action taking place within the brain which is more important than the rest, because it is more immediately essential to the continuance of life. It is that which presides over the *movements of respiration.*

We have not yet learned why these movements take place. We have only seen that they go on with a continued and harmonious action, the chest rising and falling with unfailing regularity, and the diaphragm keeping pace with it in alternate contraction and relaxation.

But these movements are neither intentional nor voluntary. They are not the result of any effort of the reason, for they are performed in the same way by idiots and by animals as by persons of mature years and the highest intelligence. Neither are they directed by the will, for they go on when we pay no attention to them and during sleep, as well as at other times. And in cases where the brain is extensively injured by violence or disease, when all the mental powers are abolished, and even volition and consciousness are suspended, the movements of respiration will often continue with the same undeviating regularity as before. The whole mass of the cerebrum and the cerebellum, and both the white and gray substance of the tuber annulare, may be compressed or destroyed without arresting this necessary function of life.

There is, however, another portion of the brain concealed in the posterior and lowermost region of the skull, which is smaller than the rest, but, at the same time, the most important of all, for it presides directly over the process of respiration. This is the ganglion of the *Medulla oblongata.*

When the other parts of the brain are injured, various nervous and mental functions are impaired or abolished, but life itself continues. When the medulla oblongata is destroyed, respiration instantly ceases, and life at the same moment comes to an end.

Accordingly, Nature has provided for the safety of this most important ganglion by burying it deeply under the remaining mass of the brain, and thus securing it from external violence. A blow upon the head which fractures the upper part of the skull may tear the substance of the brain and produce loss of memory

and unconsciousness, but it seldom or never penetrates to the medulla oblongata. Neither can this part be easily reached from below, for it rests upon the base of the skull, exactly above the summit of the spinal column. Even an internal apoplexy usually affects only the upper or middle portions of the brain. When it attacks the medulla oblongata, death is certain and immediate.

Sometimes, when the spine is fractured very high up, just at the level of its junction with the skull, the broken pieces are driven into the medulla oblongata and lacerate its substance. We then say that "the neck is broken;" and such an accident is instantly fatal, for it stops at once the movements of respiration.

In what way does this ganglion maintain the function of respiration?

162. **Reflex Nature of the Act of Respiration.**—As we have already intimated, it is by means of a reflex action. All the nerves which are distributed among the blood-vessels receive an impression from the circulating blood. As this blood loses its oxygen and becomes charged with carbonic acid, the impression is conveyed inward by the nerves, and is thus transmitted to the medulla oblongata. Among those more especially sensitive to this impression is the *Pneumogastric nerve*, which, as we have already seen, is distributed among the air vesicles of the lungs, and there perceives the earliest signs of the contamination of the blood. Arrived at the medulla oblongata, the impression thus conveyed is received by the gray matter of the ganglion; it is then converted into a motor impulse, which is sent out by the intercostal and phrenic nerves, and the muscles of respiration are at once set in motion.

The new air introduced into the lungs then relieves the nervous system by the supply of oxygen, and the muscles accordingly relax, to be again called into operation a few instants afterward by a repetition of the same process. This is the reflex action of the medulla oblongata.

Now this nervous impression is not usually felt, because it does not naturally give rise to any conscious sensation; but you can feel it very easily.

Hold the breath for a few seconds, and you are immediately conscious of an unusual sensation in the chest. This is not like ordinary pain, or the sensation of cold or heat. It is a peculiar feeling of distress, which grows more intolerable every moment. It soon fills the chest with a sense of suffocation, and then spreads over the whole body, calling loudly for air and respiration, until its demands become too imperative for resistance. When you cease from voluntary opposition, the movements of respiration begin again of themselves, and the feeling of suffocation passes off as the fresh air finds its way into the lungs.

The nervous impression, accordingly, which excites the respiratory muscles is alternately produced and relieved as the air enters and is expelled from the passages of the lungs; and the movements of respiration are repeated at regular intervals as often as they are required for the renovation of the blood.

Thus various reflex actions are performed by the nervous ganglia in different parts of the brain. Some of them are accompanied by the exercise of reason and other intellectual faculties; some of them call into operation only the powers of sensation and the will; while others, which are those most indispensable to life, go

on without our consciousness, by the simple operation of the nervous force.

We have now gone through with the study of the great nervous masses of the spinal cord and the brain, and of the nerves connected therewith. Taken altogether, they form a division of the nervous system which is called the *Cerebro-spinal* system, from the two principal nervous centres which it contains. This system presides over all those functions which connect the animal body with external objects, such as sensation, the will, the instincts, the voice, and the introduction of food and air into the body from without.

But there is another class of functions which the exclusively internal in their operation, such as digestion, absorption, secretion, nutrition, and the circulation of the blood. These functions are also regulated and controlled by a set of nerves and ganglia, with which their organs are more especially connected; and this part of the nervous system is called the *System of the Great Sympathetic.* We shall proceed to the study of this system in the following chapter.

QUESTIONS FOR CHAPTER XV.

1. Of what structures is the *brain* composed?
2. How are the two sides of the brain separated from each other?
3. How are they connected?
4. Name the three principal parts or divisions of the brain.
5. What is the form and situation of the *medulla oblongata?*
6. What important mass of gray matter does it contain?
7. Of what is it composed on its outer surface?
8. What is the situation of the *cerebellum?*
9. Of what is it composed on its outer surface?
10. What is the arrangement of the gray matter on its exterior?
11. Of what is it composed internally?

12. How are the two lateral halves of the cerebellum connected with each other?

13. What name is given to the transverse connecting band of the cerebellum? and why?

14. What is the *tuber annulare?* and why is it so called?

15. What collection of gray matter does it contain internally?

16. What are the *peduncles of the brain?* and why so called?

17. Where do the fibres of the peduncles terminate?

18. Which is the largest division of the brain?

19. What is the structure of its outer surface?

20. How are the two lateral halves of the cerebrum connected with each other?

21. Where are the *striated bodies* and *optic thalami* situated?

22. What is the function of the *cerebrum?*

23. How do we know that the cerebrum is the organ of the mind?

24. Which is the simplest and most important of the mental faculties?

25. What is the definition of memory?

26. How is the memory affected in cases of injury or deficiency of the brain?

27. What is the faculty of *judgment?*

28. What is the faculty of *reason?*

29. How are acts of an *intelligent* nature performed?

30. Do *sensation* and *volition* depend upon the cerebrum?

31. In what part of the brain do these faculties reside?

32. What is the difference between a *nervous impression* and *conscious sensation?*

33. What is the difference between *intelligence* and *volition?*

34. May an act be voluntary without being the result of intelligence?

35. What is an *instinctive* act?

36. Where is the seat of simple sensation and volition in the brain?

37. What is the most important reflex action taking place in the brain?

38. Are the movements of respiration voluntary or involuntary?

39. Do they require the co-operation of consciousness or sensation?

40. What parts of the brain may be destroyed without arresting respiration?

41. What part of the brain presides over the act of respiration?

42. How is the medulla oblongata protected by its situation?

43. What do we mean by saying that "the neck is broken?"

44. Why is this accident immediately fatal?

45. How is the reflex act of breathing performed by the medulla oblongata?

46. What nerve is the principal agent in conveying the impression to the medulla oblongata?

47. Is this impression usually perceived?

48. How can it become perceptible?

49. What muscular action is excited by it?

50. By what nerves is the stimulus carried outward to the muscles?

51. Why are the movements of respiration repeated at regular intervals?

52. What is the *cerebro-spinal* nervous system?

53. What is the general function of the cerebro-spinal nervous system?

CHAPTER XVI.

SYSTEM OF THE GREAT SYMPATHETIC.

General Structure of the great Sympathetic—its Ganglia—its Nerves.—Arterial Plexus—their Distribution—connection with the Cerebro-spinal System.—Slow operation of Sympathetic Nerves.—Effect of Cold and Wet.—Inflammation of the Internal Organs.—How to avoid the effects of Exposure.—Different kinds of Reflex Action through Sympathetic and Cerebro-spinal Systems.

163. **General Arrangement of the Sympathetic System.**—The system of the great sympathetic nerve consists of a double chain of very small ganglia, which extend from one end of the body to the other, in front of the spinal column, running through the deeper parts of the neck, and inclosed in the cavities of the chest and abdomen. The successive ganglia are connected with each other by fine nervous fibres, which run upward and downward in the direction of the chain. From the ganglia there are also given off numerous interlacing nerves, which are distributed to the great internal organs of the body—to the heart, the lungs, the stomach, the pancreas, the liver, the intestine, and the kidneys. These nerves are smaller than those of the cerebro-spinal system, and are less distinctly visible, owing to their grayish color and greater delicacy of texture.

A striking peculiarity in the course of the nerves belonging to the sympathetic system is that they follow closely the distribution of the blood-vessels. Starting from the heart, they envelop the great vessels with a sort of network, or plexus, of fine interlacing nerves,

which is called the *Arterial plexus* of the sympathetic nerves. Each plexus is re-enforced by fibres from the adjacent ganglia, and sends off corresponding divisions with the arterial branches, which follow their successive ramifications, and thus accompany them all over the body, and penetrate with them into the substance of all the organs.

In the neck and in the chest the sympathetic ganglia are regularly arranged in pairs, one on each side of the body, in front of the spinal column. This regularity is especially marked in the chest, where the ganglia are twelve in number, each one resting upon the head of the corresponding rib. But in the upper part of the abdomen their arrangement is different. Immediately behind the stomach, and about the great vessels given off from the aorta at this part, there is a collection of sympathetic ganglia varying in form and size. Of these ganglia there is one on each side, which is larger than the rest, and which, from its semicircular or half-moon shape, is called the *Semilunar ganglion.* All the ganglia are united with each other and with those of the opposite side by a network of filaments, forming a close and intricate central plexus.

From this plexus other bundles of interlacing filaments are given off, which follow the course of the blood-vessels to all the abdominal organs. It has therefore received the name of the *Solar plexus*, because the other abdominal plexuses radiate from it in every direction like the rays diverging from the sun. Thus the solar plexus holds, as it were, the central place in the nervous system of the abdomen, and by its radiating filaments controls the action of the various organs contained in the abdominal cavity (Fig. 54).

Here, also, as in other parts of the body, the sympathetic plexuses and their branches follow the course of

Fig. 54.

Course and Distribution of the Great Sympathetic.

the blood-vessels, embracing them every where with a network of intersecting fibres.

164. **Action of the Sympathetic Nerves on the Internal Organs.**—Accordingly, these nerves are every where in intimate connection with the vascular system. It is in this way that the different parts of the circulation are brought under control; so that the course of the blood may be hastened or retarded, and its quantity increased or diminished in various organs. Thus the functions of secretion, nutrition, and the like, which depend so much on the state of the circulation, are made to sympathize with each other in distant regions; and on this account the system of nerves now described has received the name of the "sympathetic" system.

The action of this system, however, and that of all the organs under its influence, is involuntary in character and entirely independent of our control.

Nevertheless, the sympathetic system of nerves is connected with the cerebro-spinal system. For each principal ganglion sends out a branch of communication which unites with another branch coming from a spinal or cerebral nerve near by; and thus the internal organs may be influenced, in a circuitous way, by impressions produced on the sensitive nerves. But this influence is always secondary and indirect in its operation.

165. **Sluggish and continued Action of the Sympathetic Nerves.**—The peculiarity of the nervous action of the sympathetic system is that it is sluggish and gradual in its operation. The cerebro-spinal nerves, on the contrary, respond instantly to the stimulus which is applied to them. The sensibility of the skin feels at once any foreign body in contact with it, and the contraction of the voluntary muscles is immediate and momentary. But in the internal organs a certain time is requisite

for the operation of the nervous stimulus; and its action, when once excited, is slow and uniform. The peristaltic movement of the intestines, for example, is not a prompt and instantaneous contraction, like that of the voluntary muscles, but a slow, continuous, and vermicular motion, by which the food is steadily and gradually carried onward.

The effect produced by the nervous action of the sympathetic system upon the internal organs often requires a still longer interval. Thus, when we are exposed to cold or dampness, we feel the impression upon the sensitive surface of the skin immediately; but the inflammation which follows in the internal organs, such as pleurisy or sore throat, only comes twenty-four hours later. And the disturbance of the circulation so produced, when once it is established, continues long after its cause has disappeared. Thus a cold or a pleurisy, which lasts a week, may be produced by an imprudent exposure which only continued for half an hour.

166. **Protection from Injury by Cold and Wet.**—Accordingly, the greatest care should be taken to avoid such unnatural exposures. The immediate discomfort and annoyance produced by cold and wet is a notice given to the nervous system that, if the exposure be continued, more serious consequences will follow, and that the internal organs will suffer in their turn. As soon as possible, therefore, after being wet or chilled, the body should be thoroughly warmed and dried. The principal danger in such cases is in delay. For cold and wet do not usually do any harm to healthy and vigorous persons *so long as the body is kept in active exercise*, and the circulation maintained in a corresponding degree of rapidity. But after the work is done, or while

the system is in repose, the same exposure that before produced only a healthy glow and reaction, if continued longer, will depress the vital powers and cause dangerous injury to the internal organs.

Thus, even at freezing temperatures, a man may walk about briskly in the open air with impunity; but sitting still in a cold room is always dangerous, and liable to produce the most serious results.

The best protection, therefore, against the consequences of an unavoidable exposure is the active employment of the muscles and limbs so long as the occasion for exposure continues; afterward the warmth of the body should be restored by artificial means with the least possible delay.

167. **Various kinds of Reflex Action.**—The sympathetic system is thus a medium of communication between the different internal organs; and, owing to its connection with the cerebro-spinal system, the internal organs are also brought into relation with the sensitive surfaces and the voluntary muscles. There are, accordingly, in the living body, reflex actions of three different kinds, which take place, in whole or in part, through the sympathetic system.

1. *Reflex actions taking place from the internal organs to the voluntary muscles and sensitive surfaces.*—The convulsions of young children are often caused by the irritation of undigested food in the alimentary canal. Attacks of indigestion will also sometimes produce temporary blindness, double vision, squinting, and even hemiplegia.

2. *Reflex actions taking place from the sensitive surfaces to the involuntary muscles and the internal organs.*—Imprudent exposure of the skin to cold and wet

will often bring on an affection of the bowels. Mental and moral impressions, conveyed through the senses, will affect the motions of the heart and disturb digestion and secretion. Terror or surprise will produce a dilatation of the pupil, and thus communicate an unusual and striking expression to the eye. Disagreeable sights or odors, or even unpleasant occurrences, in sensitive persons, will disarrange many of the internal functions of the body.

3. *Reflex actions taking place, through the sympathetic system, from one part of the internal organs to another.*—The contact of food with the lining membrane of the intestine excites the peristaltic movement in its muscular coat. The united action of the stomach, the liver, and other parts of the digestive apparatus takes place through the medium of the sympathetic ganglia and their nerves; and the vascular congestion of the different abdominal organs, at the period of their functional activity, depends upon the same influence. These actions are not accompanied by consciousness, nor by any immediate action of the cerebro-spinal system.

QUESTIONS FOR CHAPTER XVI.

1. What is the general arrangement of the great sympathetic nervous system?
2. What is the general course and distribution of the sympathetic nerves?
3. What is the *arterial plexus* of sympathetic nerves?
4. What is the arrangement of the sympathetic ganglia and nerves in the neck and in the chest? in the abdomen?
5. What is the situation of the *semilunar ganglion*?
6. What is the *solar plexus* of the sympathetic?
7. Over what functions does the sympathetic system preside?
8. Why is it called the "sympathetic" system?
9. Is the action of the sympathetic system voluntary or involuntary?

10. How is the sympathetic system connected with the cerebro-spinal system?

11. How does the action of the sympathetic system differ from that of the cerebro-spinal system?

12. What injurious effects are liable to be produced on the internal organs by exposure of the body to cold and wet?

13. What precaution should be taken to avoid these effects?

14. What reflex actions take place wholly or in part through the sympathetic system?

CHAPTER XVII.

THE SPECIAL SENSES.

Definition of the Special Senses.—Nerves of Special Sense.—Organs of Special Sense.—THE SENSE OF SIGHT.—Optic Nerve.—The Eyeball—its different Parts.—Field of Vision.—Line of distinct Vision.—Estimation of Distance.—Solidity and Projection.—Stereoscope.—Thaumatrope.—Internal Impressions.—Muscles of the Eyeball.—Eyelids.—The Tears.—Winking.—Meibomean Glands.—Lachrymal Canal.—Practices injurious to the Sight.—SENSE OF HEARING.—Auditory Nerve.—Labyrinth.—Tympanum or Drum.—Chain of Bones.—Eustachian Tube.—External Ear.—Direction, Contrast, and Pitch of Sounds.—SENSE OF SMELL.—Olfactory Nerves.—Nasal Passages.—Turbinated Bones.—Two kinds of Sensibility in Nose.—Uses of the Sense of Smell.—SENSE OF TASTE.—Papillæ of Tongue.—Two kinds of Sensibility in Tongue.—Glosso-pharyngeal Nerve.—Uses of the Sense of Taste.

THE last department of the nervous system which we shall study is that of the **Special Senses.** By this term we mean the senses which give us the feeling of certain sensations different from those of ordinary touch, such as the sensation of light, of sound, of odors, or of taste.

168. **Nerves of Special Sense.**—Each special sense has a nerve which is devoted to it, and which is called the *Nerve of special sense.* Each one of these nerves is so constituted that it can feel the particular sensation with which it is connected, but can not perceive any of the others. Thus the nerve of the eye is sensitive to light, but not to sound; and the nerve of the ear is sensitive to sound, but not to taste or odors. Each nerve, there-

fore, is endowed with a special sensibility, which fits it to perform a special function.

169. **Organs of Special Sense.**—For every special sense there is also a peculiar organ, of more or less complicated structure, to which the nerve is distributed. This is called the *Organ of special sense.* Thus, for the sense of smell, we have the nose; for that of taste, the tongue; for that of sight, the eye; and for that of hearing, the ear. Each organ of special sense, beside its nerve, is provided with blood-vessels, lining membranes, muscles, and other parts, which assist in the performance of the entire function.

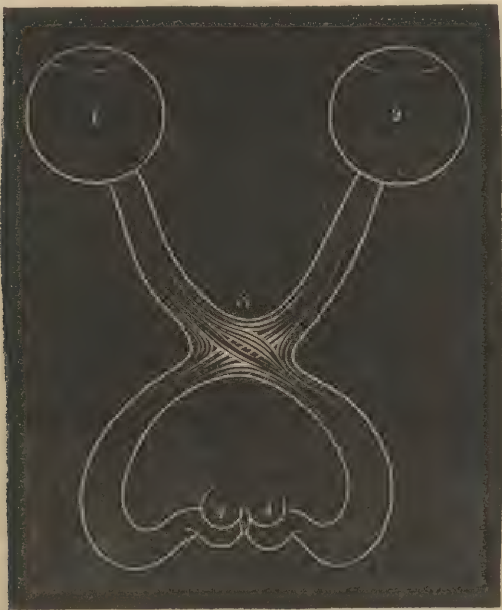
We shall examine in succession, 1st, the sense of Sight; 2d, that of Hearing; 3d, that of Smell; and, 4th, that of Taste.

170. **The Sense of Sight—Optic Nerve.**—We are enabled to perceive the impression of light by means of a peculiar nerve, situated at the base of the brain, which is called the *Optic nerve.* This nerve originates on each side from a pair of rounded ganglia, situated between the cerebrum and the cerebellum, which are the ganglia of the sense of sight (Fig. 53 [5]). From their giving origin to the optic nerves, and from their having the form of small rounded prominences, they are called the "optic tubercles." From these ganglia the optic nerves curve outward and forward, embracing the peduncles of the cerebrum, and, continuing their course along the base of the brain, leave the cavity of the skull, each by a rounded opening called the "optic foramen," and terminate in the back part of the two eyeballs.

But about the middle of their course these nerves present a remarkable connection or union with each

other upon the median line. They approach each other on each side, until they at last meet and become consolidated into a single mass. At this point there is an interchange of fibres between the two nerves, so that some of the fibres belonging to the right optic nerve pass over to the left side, and some of those belonging to the left optic nerve pass over to the right side. This is called the *Decussation of the Optic Nerves* (Fig. 55).

Fig. 55.



Course of the Optic Nerves in Man.—1, 2. Right and left eyeballs; 3. Decussation of the optic nerves; 4, 4. Optic tubercles.

At this point there is also a connection between the two optic tubercles, some of the fibres passing directly across, behind the decussation, and returning to the op-

tic tubercle of the opposite side; and also a connection between the two eyeballs, as some fibres pass directly across, in front of the decussation from side to side. Thus the eyes are not so much two distinct organs as one double organ, both parts of which are associated in the performance of a single function.

From the place of decussation the optic nerves again diverge, and, passing through the optic foramina, reach the eyeball. Here each nerve spreads out into a thin, delicate, grayish expansion of nervous matter, which lines most of the interior of the eyeball. This expansion is called the *Retina*. It forms the termination of the optic nerve.

171. **Function of the Optic Nerves.**—The optic nerves are the conductors of the sense of sight. When a ray of light falls upon the retina, the impression is conveyed inward along the fibres of the nerve until it reaches the gray matter of the optic tubercle. There it becomes a sensation, and we consequently perceive the impression of light coming from without. We also perceive its variations of intensity and color, whether it be strong or feeble, and whether it be blue, yellow, or red.

Accordingly, if the optic nerves be divided or destroyed by disease, complete blindness is the result. For the impressions of light can no longer reach the optic tubercles, and therefore produce no sensation.

An important reflex action also takes place in the optic tubercles. Whenever a strong light falls upon the retina the pupil of the eye is immediately contracted; if the light be diminished in intensity, the pupil again enlarges. The stimulus of the light, conveyed inward by the optic nerve, is converted into a reflex action by the optic tubercles, and is thence directed

outward by certain motor nerves to the muscular fibres which serve to contract the pupil. This shows what is called the "sensibility of the pupil." It is an involuntary action, and will take place even in a state of unconsciousness, provided the optic tubercles, as well as the nerves, be uninjured.

172. **Structure of the Eyeball.**—Thus far the apparatus of vision consists only of a sensitive nerve and a ganglion, destined to convey and to receive the simple impression of the light. But, in order to understand the means by which the sense of sight is exercised in all its perfection, we must examine the special organ to which the optic nerve is attached. This organ is the *Eyeball.*

The eyeball is a firm globular mass, situated in the bony cavity beneath the forehead which is called the "orbit." Only a small part of the front of the eyeball is visible between the lids; but by placing the fingers over the eyelids, and between it and the bones of the orbit, we can easily feel its globular form. It consists externally of a strong and opaque white fibrous membrane, which envelops the internal parts like a sac or bag. This is called, from its hard and resisting texture, the *Sclerotic coat* of the eyeball.

The sclerotic coat extends all over the surface of the eyeball, excepting just at its front part. Here there is a circular spot, about one fifth of the whole surface of the eyeball, at which the white and opaque sclerotic is replaced by a firm but perfectly transparent and colorless membrane, through which the light gains admission into the interior of the eye. In texture and appearance this part of the eye is like a colorless and transparent piece of horn or tortoise-shell, and it is

therefore named the *Cornea.* In looking directly at the eye from the front, we do not observe the cornea, since, on account of its transparency, we see only the colored parts of the eye behind it. But if we look closely at the eye of another person in profile, we shall see the glassy surface of the cornea projecting in a rounded form in front of the other parts.

The eyeball, accordingly, is covered every where by a dense and resisting envelope, of which the front portion, or the cornea, is colorless and transparent, while that on the sides and back, or the sclerotic, is white and opaque.

It is therefore like a room with one window. The light will penetrate through this window and strike upon the back wall of the room, but it can not enter through any openings or crevices at the side.

Immediately underneath the sclerotic is a second coat or membrane of the eyeball, called the *Choroid coat*, of a brownish black color. It is quite opaque, like the sclerotic, but is much softer in consistency, and is abundantly supplied with blood-vessels. The choroid is exceedingly important in the eye, to absorb the light which reaches it and prevent reflections; for such reflections would interfere with the distinctness of illumination at the bottom of the eye. If you look at a glazed picture at a little distance, with the light coming from a window directly behind, you can not see the picture distinctly, owing to the reflection of light from the surface of the glass. For the same reason, spy-glass and microscope makers have learned to cover the inside of their tubes with a layer of soft black paint, so that all the light may come in a direct line through the glass lenses, and none be reflected from the sides of the

instrument. The choroid membrane serves a similar purpose in the eye.

Beneath the choroid membrane comes the *Retina.* This, as we have already said, is the termination of the optic nerve, and consequently the most important part of the whole eyeball. As the nerve penetrates the back part of the eyeball, it passes through both the sclerotic and choroid coats, and then spreads out in a thin, soft, delicate, and semi-transparent layer, which lines the whole internal surface of the eyeball except in front, just at the opening of the cornea. The retina is the sensitive part of the eye. It is this membrane which receives the rays of light entering at the front, and communicates their impression, through the fibres of the optic nerve, to the brain behind. But, though the retina is so sensitive to light and color, it can not convey the ordinary sensations of touch. Even when the membrane itself is cut or pricked, as in surgical operations about the eye, it does not convey the feeling of a touch or a wound, but only the sensation of a flash of light. It is for this reason that a sudden blow upon the eyeball produces the appearance of an explosion of brilliant sparks. When the deeper parts of the eye are inflamed or otherwise disordered, the patient sometimes sees irregular flashes and points of light, owing to the unnatural irritation of the retina; and when this membrane is deeply injured by disease, it becomes insensible, and the eye is consequently blind.

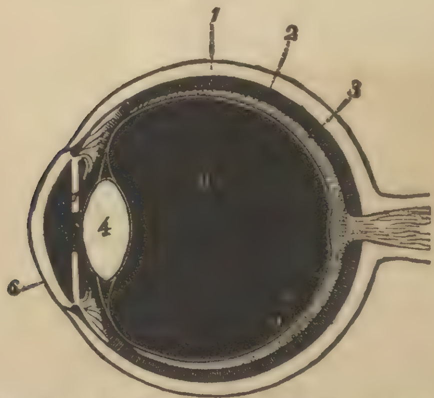
Owing to the special sensibility of the retina, therefore, its function is exclusively devoted to the perception of light which reaches its surface from without.

The globular cavity inclosed by the retina is occupied by a transparent, jelly-like substance, which is

termed the *Vitreous body*, from its colorless and glassy appearance. It fills the interior of the eye, and keeps the other parts in their places by preserving the tension of the external coats.

173. **Crystalline Lens.**—Just in front of the middle of the vitreous body is another transparent and extremely important part of the eye, which is called the *Crystalline lens.* It has the form of a circular, flattened glass bead, thicker in the middle and thinner at its edges. The lens is suspended in its position by a very thin and delicate membrane, which envelops its surface both in front and behind. It then stretches outward from the edges of the lens in a double layer, which soon after consolidates into a single membrane, called the "hyaloid membrane," and in this form it extends over the whole surface of the vitreous body. The crystalline lens is thus held in its place in front of the central part of the vitreous body (Fig. 56).

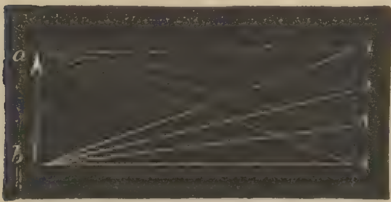
Fig. 56.



Vertical Section of the Eyeball.—1. Sclerotic; 2. Choroid; 3. Retina; 4. Lens; 5. Hyaloid membrane; 6. Cornea; 7. Iris; 8. Vitreous body.

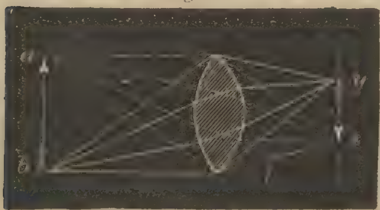
174. Function of the Crystalline Lens.—Now it is only by means of the crystalline lens that we are enabled to perceive the *form and outline of things.* For the retina itself is only sensitive to the impressions of light and color; that is, it can perceive the difference between light and darkness, and between the different colors, as red, blue, yellow, and green. But it has no power, by itself, of distinguishing the form of objects. The eye receives the light indifferently from every part of an object which may be situated in front of the cornea; and therefore, if it were provided with the retina alone, the rays of light from all parts of the object, diverging equally in every direction, would enter the eye and reach together every part of the retina, as in Fig. 57, where the arrow, *a*, *b*, represents the object, and the dotted line at the right represents the retina. Here all parts of the retina, 1, 2, 3, 4, would receive rays coming both from the point of the arrow, *a*, and from its butt, *b*. Thus the top, bottom, and sides of the object would all be indiscriminately mixed at the surface of the retina; and we should not be able to distinguish its different parts, but should only receive the impression of a confused luminosity.

Fig. 57.



Vision without a Lens.

Fig. 58.



Vision with a Lens.

A "lens" is any transparent body, having the figure described above, that is, rounded on its two opposite surfaces and thinner at its edges, which has such an action on the rays of light passing through it that it brings them together or concentrates them at a certain distance beyond. Consequently, any brilliant point situated in front of such a lens will produce another brilliant point behind it; because its rays, which diverge in order to reach the lens, are again brought together by passing through it. We can see this effect with any convex lens of glass, such as the large magnifying glasses which are used for looking at pictures.

If you hold a white screen or a sheet of paper at a distance of six or eight feet from a gas-light, the whole surface of the paper is equally and moderately illuminated, because the light, coming from all parts of the flame, is spread uniformly over its surface. But if you hold a lens between the light and the paper, you will see that it makes a spot which is brighter than the rest; and as you bring the lens slowly nearer and nearer to the paper, the middle of this spot grows brighter and brighter, until at last you have a distinct and brilliant image of the flame in its centre, while the surrounding parts are dark. Not only all the light passing through the lens is thus brought together in a small space, but all the light coming from the top of the flame is concentrated at one point, and all that coming from its bottom is concentrated at another; so that we can now distinctly perceive its form and outline.

The crystalline lens performs the same service in the interior of the eye. With the lens interposed, all the rays emanating from the point of the arrow, a (Fig. 58), are concentrated at x, and all those emanating from its

butt, *b*, are concentrated at *y*. Thus the retina receives the impression of the point of the arrow separately from that of its butt, and all parts of the object in like manner are distinctly and accurately perceived.

The retina, accordingly, is the sensitive screen upon which the light is thus concentrated.

The spot at which a lens will thus concentrate the light passing through it is called its *focus*, and it is only at a certain distance that this concentration will be perfect. If we move either the screen or the lens backward or forward, so as to increase or diminish the distance between them, the brilliant spot fades away, to reappear when the two are again placed in their proper position. Now the crystalline lens is naturally placed at such a distance from the deeper parts of the eye that it concentrates the light to a focus exactly at the surface of the retina.

175. **Iris and Pupil.**—In front of the crystalline lens there is suspended a muscular curtain with a circular opening or perforation at its centre. This curtain or partition is the *Iris*. It is so called on account of its variations of color, its surface presenting a mixture of different tints, which produce, all together, the effect of black, brown, blue, or gray. This is the colored circle which we see behind the transparent cornea, and the circular opening in its centre is the *Pupil*.

The iris is composed of fine muscular fibres, which are arranged in two sets. Those of the first set radiate from the edges of the pupil outward, and serve to enlarge the opening. The second run circularly round the pupil, and serve to draw it together like the mouth of a purse. The posterior surface of the iris is covered with a layer of black coloring matter like that of the

choroid coat. The iris itself is therefore opaque, and it admits the light to the interior of the eye only through the opening of the pupil.

176. **Movements of the Pupil.**—The pupil, however, is movable. By the alternate action of the circular and radiating fibres of the iris, its opening may be enlarged or diminished, and a greater or smaller quantity of light admitted to the eye. We have already described the reflex action by which this is accomplished. When the light which strikes the retina is intense and dazzling, the pupil contracts and shuts out a portion of it; when the light is dim and insufficient, the pupil enlarges and admits it in greater abundance.

Accordingly, when we suddenly enter a brilliantly lighted apartment, the eye is at first dazzled by the intensity of the light; but it soon accommodates itself to the change by the contraction of the pupil, and the light no longer produces discomfort. On the other hand, on first passing from the light into a dark room, every thing is in obscurity, and none of the objects in the apartment are visible to us. But as the pupil enlarges and more light gains entrance to the eye, the various objects become perceptible, until the room, which before appeared in total darkness, at last seems to be tolerably well lighted.

This reflex action of the pupil takes place through a part of the sympathetic system. In the back part of the orbit of the eye there is a minute nervous ganglion, called the *Ophthalmic ganglion*. It communicates by slender filaments with the arterial plexus of the sympathetic nerve in the interior of the skull, and also with motor and sensitive branches of the cranial nerves. From its front part there pass off from ten to fifteen

delicate nerves which soon penetrate the sclerotic coat of the eyeball, and run forward beneath it until they reach the situation of the iris. These are called the *Ciliary nerves.* They are finally distributed to the muscular fibres of the iris, and alternately excite them to contract or enlarge the pupil.

The movement of the pupil is therefore one of those reflex actions which take place partly through the cerebro-spinal and partly through the sympathetic system of nerves. The impression upon the retina is first carried to the optic tubercle in the brain, while the impulse reflected thence is conveyed to the ophthalmic ganglion, and finally reaches the muscular fibres of the iris through the ciliary nerves.

Between the front of the iris and the inner surface of the cornea is a space which is filled with a thin transparent fluid. From its watery consistency this fluid has received the name of the *Aqueous humor.* It completes the structures entering into the composition of the eyeball.

There are several peculiarities in the function of the eye which require attention.

177. **Field of Vision.**—First, *there is only a small space in front of the eye in which objects can be seen distinctly.* As the pupil will admit rays of light coming obliquely from various directions, there is, of course, a field or circle, of a certain size, within which objects can be perceived. This space is called the *Field of vision ;* and beyond its limits nothing whatever can be seen, because rays of light coming directly from the side or from behind can not enter the pupil.

178. **Line of distinct Vision.**—But even within this field there is only a single spot in its centre at which

objects can be seen distinctly. Thus, if we stand in front of a row of upright stakes or poles, we can see those directly before the eye with perfect distinctness, but those placed at a little distance on each side are only perceived in a confused and uncertain manner. We can see that they are there, but we can not accurately distinguish their outlines.

When we look at the middle of a printed page, directly in front, we see the distinct forms of the letters; but at successive distances from this point, if the eye be kept fixed, we can distinguish first only the separate letters with confused outlines, then only the words, and, lastly, only the lines and spaces.

This is because the rays of light which enter the crystalline lens directly from the front (as from *a*, Fig.

Fig. 59.

Lines of Distinct and Indistinct Vision.

59), are concentrated by it to a focus at the retina (x), and produce distinct vision; but those which enter it

very obliquely (as from *b*), cross each other in the cavity of the eyeball, and so reach the retina separately (at *y*, *z*), thus producing indistinct and imperfect vision.

There is, therefore, only a single line extending directly in front of each eye within which objects are distinctly seen. This is called the *Line of distinct vision.*

We make up for this, however, by the great mobility of the eyes, which turn rapidly toward every part of a landscape, and in this way enable us to see the whole with distinctness. In reading a printed page, also, the eyes follow the lines from left to right, thus seeing each letter and word distinctly in succession. At the end of each line they return suddenly to the commencement of the next, and repeat this movement from the top to the bottom of the page.

179. **Single and distinct Vision with both Eyes.**—Beside this, even directly in front of us, *there is only a certain distance at which objects can be seen distinctly by both eyes.* As the eyes are situated two or three inches apart from each other in their orbits, when they are both directed toward the same object, the lines of vision for the two eyes converge and meet each other at the situation of the object. It is for this reason that we see only one object, though we look at it with two eyes; for, as the two lines of vision meet at a single point, the two distinct images exactly cover each other, and so form but one (Fig. 60 [1]).

But either within or beyond this point, vision becomes imperfect and at the same time double. If we hold up one of the fingers before the face at the distance of one or two feet, and in the same range with any small object, such as a door-knob, on the other side of the room, when both eyes are directed at the finger,

we see it single and distinctly, but the door-knob appears double, one image on each side the finger. If we now change the direction of the two eyes and look at the door-knob, that, in its turn, will become distinct and single, while the finger will appear double, one on each side the door-knob.

Fig. 60.

Vision at different Distances.—*a*. Right eye; *b*. Left eye; 1. Near object; 2. Remote object.

This is because, when both eyes are directed at the nearer object (Fig. 60 [1]), the farther one [2], will also be seen; but it will be seen indistinctly, because it is outside the line of distinct vision. But for the right eye it will be to the right of the line of vision, and for the left eye to the left of this line. The two images, therefore, do not correspond in situation, and the object consequently appears double.

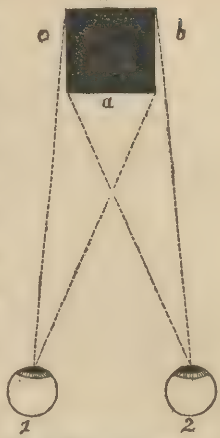
In looking at a landscape, accordingly, when both eyes are directed at the foreground, the middle ground and the distance both appear dim and indistinct; and when the eyes are directed toward the distance, the foreground, in its turn, is imperfectly perceived.

Thus we judge instinctively of the distance of different objects by the direction of the two eyes and their lines of distinct vision.

180. **Appreciation of Solidity and Projection.**—But the combined action of the two eyes is also useful in another respect: it enables us to appreciate the qualities of *solidity and projection.*

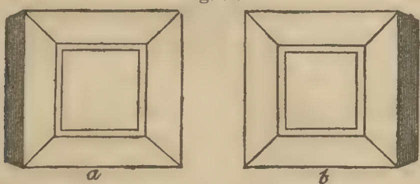
When we look at any solid object, such as a square box (Fig. 61), at a short distance in front of us, the two eyes, being separated from each other by the distance between their orbits, will see the object from two different directions. Both of them will see the front of the box (*a*), but, in addition, the right eye will see a little of its right side (*b*), and the left eye will see a little of its left side (*c*.) We can easily convince ourselves of this, in looking at such an object, by alternately closing first the right and then the left eye (as in Fig. 62), when we shall find that to the left eye the box appears as at *a*, and to the right eye it appears as at *b*.

Fig. 61.



Vision of Solid Objects.—1, 2. Right and left eyes; *a*, *b*, *c*. Solid object.

Fig. 62.



Solid Object.—*a*. As seen by the left eye; *b*. As seen by the right eye.

Consequently, the images of such a solid object, as perceived by the two eyes, are different. But as they are both in the line of distinct vision, and occupy the same spot, they are united with each other, and appear as one. It is from this union and fusion of two different images that we acquire the perception of solidity and projection.

Accordingly, a flat picture, however well it may be painted, can never deceive us in this respect; for we feel that precisely the same image is presented to both eyes, and consequently that it can have no real projection.

But when two pictures of the same object, taken in two different positions, are presented in such a way that only one of them is seen by the right eye and only the other by the left, the same effect may be produced as by the object itself, and the appearance of solidity and projection may be perfectly imitated.

This is actually accomplished in the contrivance known as the *Stereoscope.* This is simply a box holding two pictures, usually photographs, of the same object. One of the photographs, taken as the object would actually appear to the right eye, is seen by the right eye; and the other, taken as it would appear to the left eye, is seen by the left eye. Thus the two pictures combined seem to be but one, and a singularly deceptive resemblance to the real object is produced.

Thus, within moderate distances, we perceive the projection of solid bodies by the combined action of the two eyes. We also perceive variations in distance by the different direction of the two lines of vision and the angle at which they meet. But at long distances both these distinctions cease; because the direction of the two eyes is then so nearly parallel that we can not perceive the difference between them. The colors of objects also become less brilliant as they are removed from us, and are also changed somewhat by the intervening atmosphere. We can perceive, accordingly, the solidity and variation in color of a rock, a tree, or a house near by; but at a distance of some miles, even a large object,

such as a mountain, loses its projection, and appears flat and gray against the horizon.

181. **Effect of Contrast in Light and Color.**—Secondly, the strength of the impressions which we obtain by the sight depends upon their *contrast.* The lighted parts of a solid object appear not only more brilliant, but also of a different color from those which are in shadow; and the greater the contrast between these tints, the more readily we distinguish its different parts. The strongest of all contrasts is that between black and white, and therefore we very easily read a printed page, which is composed of black letters on a white ground. It is still easier to distinguish white letters on a black ground, because the eye is more attracted by the white surface which is lighted than by the black surface which is dark. Different colors are also modified in their appearance by other colors with which they are associated. Thus a white surface will look blue by contrast with yellow or orange, and will assume a rosy tinge by contrast with green. If we look through blue spectacles, every thing will at first sight appear to be tinged with the blue color of the glass; but this impression will after a time pass away, and when the spectacles are again removed, surrounding objects will look yellowish by contrast.

When different colors are closely mingled together they produce an intermediate tint. Thus blue and yellow, when intimately mixed, produce green; yellow and red produce orange; red and blue produce purple; and white and black grains, uniformly mingled, have the appearance of a continuous shade of gray.

182. **Persistence of Visual Impressions.**—Thirdly, *vivid impressions produced upon the eye remain for a short*

time afterward. If a lighted stick be swung round rapidly in a dark room, it appears like an unbroken circle of light. This is because the impression of the light, at any one point in the circle, remains until the revolving stick has again returned to the same spot; and a succession of sparks, sent off rapidly from a knife-grinder's wheel, produce the appearance of a continuous stream of fire. This is also illustrated by a familiar toy called the *Thaumatrope.* In this instrument a series of pictures of the same object in different positions, as of a horse leaping over a wall, are made to pass successively before the eye upon a revolving card. The different figures follow each other so rapidly that the eye can not perceive the interval between them, and they look like the same figure in active motion.

183. **Visual Impressions of Internal Origin.**—Finally, the impressions of sight *may be imitated by the internal action of the nervous system*, so that we appear to see objects which are not presented to the eyes. This is also true of all the other senses, but the internal impressions belonging to the sense of sight are much more vivid than the rest. Thus, in a dream, or even in a reverie, we often see external objects, with all their peculiarities of light, color, and form, nearly or quite as distinctly as when awake, and much more distinctly than we perceive imaginary sounds or sensations of touch. It is this sense also which becomes most easily excited in certain nervous disorders, as in delirium, when the patient sees passing before his eyes faces, and figures, and landscapes, and towns, and cities, which are depicted upon his imagination with a remarkable force and distinctness.

As the sense of sight, therefore, does not depend so

directly as the other senses upon the actual contact of external objects, it is more readily called into activity when withdrawn from their influence.

The organ of sight is provided with certain accessory parts, which enable it more perfectly to perform its functions.

184. **Movements of the Eyeball.**—In the first place, the eyeball is *movable* within the orbit. It rests in this bony cavity, imbedded in a layer of fat, which acts like a soft and elastic cushion; and upon this cushion the eyeball is capable of turning in various directions. From the bony walls at the bottom of the orbit four slender muscles pass forward in a straight direction to be inserted into the sclerotic coat—one above, one below, one on the inside, and one on the outside of the eyeball. These are the "straight muscles of the eyeball." As they contract, they turn the eye upward or downward, inward or outward. Another muscle, very curiously constructed, is called the "upper oblique muscle of the eyeball." It arises, like the rest, from the back part of the orbit, and runs forward until it reaches its upper and inner portion near the bridge of the nose. Here the tendon passes through a fibrous loop attached to the bone, and then turns backward and outward, to be inserted into the upper part of the sclerotic coat near its middle. The tendon and the fibrous loop thus form a pulley, through which the muscle acts upon the eyeball. It is therefore sometimes known by the name of the "trochlearis," or pulley-like muscle. Finally, a sixth, or the "lower oblique muscle," starts from the inner and lower part of the orbit, and winds outward beneath the eyeball, to be attached to the sclerotic at its outer part, nearly opposite the insertion of the trochlearis.

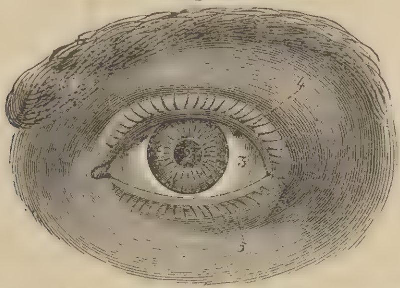
The two oblique muscles rotate the eyeball upon its axis. If you stand in front of a mirror and incline the head gently from side to side, you will see that the eyes turn at the same time in the opposite direction, revolving easily in their orbits, so that each eye keeps its own level with the horizon. This is accomplished by the action of the oblique muscles. All the muscles of the eyeball, by this combined or alternate contraction, thus enable the eye to move in various directions, and both enlarge the area of sight and assist in the expression of the face.

185. **Protection of the Eyeball from Injury.**—The eyeball is protected from external injury by the bony edges of the orbit. These are so arranged that, with the cheek-bones and those of the nose, they form a nearly continuous ridge or rampart about the front of the eye. A blow with a stick or other weapon, therefore, hardly ever injures the eyeball, because it is caught by the projecting edges of this ridge. In order to reach the eye itself, the missile or weapon must be directed in a nearly straight line from before backward; and as this seldom happens, the eye usually escapes injury.

186. **The Eyelids and their Movements.**—In front of the eyeball are the *Eyelids.* These are two horizontal curtains or folding-doors, which open and shut to admit or exclude the light. Each is strengthened by a thin but firm cartilaginous plate, situated beneath the skin. The upper eyelid is much the larger and more movable of the two, and when the eyes are opened it is raised by a muscle attached to its upper edge, and drawn in beneath the roof of the orbit. When allowed to fall, it covers the whole of the pupil and the greater

part of the cornea. It is therefore like a screen or Venetian window-blind, which may be raised or lowered at will in front of the transparent parts of the eye (Fig. 63).

Fig. 63.



External parts of the Eye.—1. Iris; and, 2. Pupil, showing through the transparent cornea; 3. Front part of sclerotic coat, seen between the lids, and called, from its white color, the "white of the eye;" 4. Upper eyelid; 5. Lower eyelid.

The inside of the eyelids are lined by a thin and transparent membrane, called the *Conjunctiva*, which also extends over the whole exposed portion of the eyeball. The conjunctiva is supplied with a very important watery secretion, by which its surface is constantly bathed, and its brilliancy and transparency kept unimpaired. This secretion consists of the tears. They are produced in a little gland, termed the "Lachrymal gland," situated in the upper and outer part of the orbit, and are conducted thence by a number of fine ducts, which open upon the conjunctiva near the outer corner of the eye. The watery fluid then runs along the edge of the lower eyelid toward the inner corner of the eye.

187. **The act of Winking.**—But about five or six times a minute the tears are spread over the surface of the conjunctiva by the act of winking. This motion is performed by means of an oval shaped muscle, situated

immediately beneath the skin of the eyelids, which surrounds their opening with a thin and broad layer of circular fibres. This is the *Orbicularis* muscle, so named from its orbicular or ring-like form. By its contraction it suddenly draws the eyelids together, and, as they instantly separate, they distribute the tears in a thin layer over the surface of the conjunctiva.

This motion is extremely important. For, as the front surface of the eyeball is constantly exposed to the air, it loses its moisture by evaporation, and would soon become dry, wrinkled, and opaque. It is for this reason that immediately after death the eye becomes dull and tarnished, and loses its natural appearance of brilliancy. But during life the orbicularis muscle is constantly watching for the safety of the eyeball; and every few seconds, as soon as a little collection of the tears has accumulated below, it brings the eyelids together with a quick, sharp motion, catches the watery fluid upon their edges, and so spreads it equally over the surface of the cornea.

The motion of winking is a reflex action. It takes place, as a general rule, without our knowledge, and it is even difficult to resist it, for a long time, by any voluntary effort. It is so rapidly performed that it does not usually attract our notice. For we have already seen that visual impressions made upon the eye remain for a very short time afterward; and though the lids are closed by each act of winking, the motion is so instantaneous that it does not interrupt the sensations of the eye, and it therefore passes unobserved.

188. **The Meibomean Glands and their Secretion.**—In order to prevent the tears from being lost by running over the eyelids, the edges of the lids are smeared with

a thick oleaginous secretion, like the "sebaceous matter" of the skin. Oily matters and water have such a repulsion for each other, that a little grease, rubbed on the edges of a cup, will retain the water and prevent its running over, though the cup may be filled even above the level of its brim. The same office is performed by the oily secretion of the eyelids. It is supplied by a number of long slender glands, called the *Meibomean glands*, surrounded with clustered follicles, which are situated on the inside of each eyelid directly beneath its lining membrane. They open by fine orifices along the margin of the lid, and keep this part covered with a thin layer of their secretion.

Usually the sebaceous matter is sufficient to keep the tears within the eyelids; but the lachrymal glands are very sensitive to peculiar mental emotions. These emotions, by the sympathetic action of the nervous system, sometimes excite the glands to unusual activity, so that they pour out their secretion in increased abundance; and the tears, thus discharged in excessive quantity, run over the edge of the eyelids, and trickle down upon the cheeks and face. This is the act of weeping.

189. **Passage of the Tears into the Cavity of the Nostrils.**—From the front of the eye, the tears are collected by a minute orifice at the inner corner of each eyelid. These two orifices lead into two narrow tubes or canals, called the *Lachrymal canals*, which convey the tears into an enlarged cavity or sac at the upper and outer part of the nose. This sac is continued downward into a duct, called the "nasal duct," which opens into the interior of the nose, about its middle portion. Thus the tears, after performing their part in the protection of the eyeball, are conducted through the lachrymal

passages, to be finally discharged into the cavity of the nostrils.

190. **Sensibility of the Conjunctiva.**—The surface of the conjunctiva possesses an extreme sensibility. This is not like the sensibility of the touch, but rather an irritability like that of the glottis, by which the conjunctiva resents the intrusion of foreign substances between the eyelids. It is protected from this intrusion by the activity of the orbicularis muscle, which contracts spasmodically, and shuts the lids on the least approach of external objects to the eye. It is still farther protected by the *Eyelashes.* These are the stiff curved hairs which grow from the outer margins of the lids, and project forward in front of their openings. Those of the upper lid are curved upward, those of the lower lid are curved downward; and when the lids are brought near together, these two ranges of hairs stand like so many crossed sabres, or a kind of chevaux-de-frise, guarding the entrance to the eye.

But if any foreign body should accidentally gain admission, then the sensibility of the conjunctiva is excited. Every one has felt the extreme irritation produced by the entrance of a grain of dust, or a cinder, or the filing of a metal, beneath the eyelids. The front of the eyeball becomes blood-shot, the tears are poured out in abundance, the movements of winking follow each other with rapidity, and the attention is distracted from every other object by the discomfort of the suffering organ.

This irritability of the conjunctiva is the safeguard of the eye. For if the foreign substance were allowed to remain, it would produce, after a time, a serious injury to the deeper parts, and thus permanently impair

the sight. These deeper parts, although so important, are themselves insensible. But the conjunctiva stands in front of them, to give us notice of the approach of danger; and when the foreign body is not immediately discharged, this membrane is thrown into an excessive irritation, and gives us no rest until we have rid ourselves of the offending substance, and relieved the eye from the danger of its presence.

191. **Precautions proper to be observed in using the Eyes.**—The eye, like other bodily organs, is susceptible of fatigue. After being exposed for a considerable time to a bright light, this fatigue is very perceptible, and the optic nerve is refreshed by the repose of twilight or of a shaded apartment. There is no doubt that the regular refreshment of sleep during night is also necessary to the sense of sight as it is to the muscular system; and this, the most delicate and valuable of all the senses, is the most readily impaired by an unnatural want of sleep.

The sight may also be injured by excessive or improper use during the day.

This effect may be produced, first, by exposure of the eye to *too brilliant a light.* If we look for an instant at the sun, or even at an excessively strong artificial light, we feel for some seconds afterward that the eye is partially blinded. It can no longer distinctly perceive surrounding objects; and if we have been so imprudent as to continue the unnatural exposure, its blinding effect lasts for a long time afterward. The eye may even be permanently injured by too violent or long-continued a stimulus of this kind.

Secondly, the eye should not be employed for too long a time in *the close examination of small objects.*

Very small objects, seen at a short distance, require a greater exertion of the eye than larger ones which are more easily perceived. Thus it is exceedingly wearisome and injurious to read a book which is too finely printed, or in which the letters are too close together, or not sufficiently distinct. It is the worst possible economy, therefore, to read habitually books which are badly printed; for it is at the expense of the eyesight, which can not be replaced when once seriously impaired.

But the examination of minute objects, or the employment of the eye in reading or writing, is much more injurious when continued *with insufficient light.* The light, of course, should never be dazzling, but it should always be sufficient to illuminate fully the printed page or other object which is under examination. Otherwise the eye becomes strained and wearied beyond its natural power of endurance, and a repetition of such treatment will inevitably impair the sight. It is for this reason that reading by twilight is particularly dangerous; because the light fades at that time slowly and imperceptibly, and thus becomes exceedingly insufficient before we notice its diminution.

The light which is used should also be perfectly *uniform and steady.* The diffused light of day is therefore the best for reading or writing. A flickering and uncertain artificial light, on the other hand, is the worst; for its rapid and irregular changes from brightness to obscurity fatigue the optic nerve, and rapidly exhaust the sensibility of the eye.

The use of the eye in studying minute objects should therefore be employed with moderation, and in such a way as to save the organ from unnatural irritation or fatigue.

192. **The Sense of Hearing.**—Sound is produced by the vibration of the atmosphere. Many solid bodies also are capable of vibrating, such as a metallic bell or the strings of a violin; but their vibration must be communicated to the atmosphere in order to reach our ears and thus produce the sensation of sound. Accordingly, if a bell be rung under the receiver of an air-pump from which the air has been exhausted, it produces no sound. The metal itself may vibrate as usual, but its movements can not be communicated to the atmosphere, and consequently can not reach our organs of perception.

Hearing is therefore the sense by which we perceive the sounds which are conducted by the atmosphere.

193. **Auditory Nerve.**—The sense of hearing depends upon a special nerve, called the *Auditory nerve.* This nerve originates from the upper and back part of the medulla oblongata, whence it passes outward, curves round this portion of the brain, and, after a short passage, penetrates by a rounded opening into a thick and triangular portion of the floor of the skull. This part of the bony walls of the cranium is much denser and harder than the remainder, and has therefore received the name of the "stony" or "petrous" bone.

Within the petrous bone the auditory nerve presents a singular and complicated form.

194. **The Labyrinth.**—It lies in a cavity which is excavated in the substance of the bone, and in which it is protected from external injury by the thickness and density of the bony walls. This cavity, from its remarkable and varied configuration, is called the *Labyrinth.* It consists, first, of a small rounded chamber, which serves as a kind of entrance or ante-room to the remainder, and is therefore termed the "vestibule." The

vestibule communicates with three narrow curved passages, called the "semicircular canals." These canals are so placed that one is directed nearly upward and forward, the second nearly upward and sideways, while the third is horizontal. Both the vestibule and the semicircular canals are filled with a clear transparent fluid like lymph; and in this lymph there is suspended a membranous sheath or bag, which presents in its form an exact repetition of the bony cavities which inclose it, being enlarged at the situation of the vestibule, and sending out tubular prolongations into the semicircular canals. Its interior is also filled with lymph, and it thus floats in the fluid of the labyrinth, but without touching the walls of the cavity.

The auditory nerve is distributed to this sheath, its fibres spreading out in the substance of its membranous walls.

The remaining part of the labyrinth is no less peculiar in its form. Just alongside the vestibule there is a double tubular canal, which winds round a hollow central axis, making nearly three complete turns, thus forming a kind of spiral cone, like a snail-shell, with its point directed forward and outward. From its resemblance to a snail-shell, this part of the labyrinth is termed the "cochlea." The spiral canals of the cochlea, which communicate at one end with the vestibule, are themselves filled with lymph; and the remaining fibres of the auditory nerve pass upward along its hollow axis, spreading out successively in a membranous partition between the two parts of the double canal. Thus, when they arrive at the apex of the cone, the nervous fibres have all been exhausted, and the distribution of the nerve is complete.

The whole of this part of the auditory apparatus, consisting of the labyrinth, the membranous bag which it contains, with the auditory nerve and its distribution, being all contained within the bony floor of the skull, is called the *Internal ear.*

195. **Function of the Auditory Nerve.**—The auditory nerve, like the optic, is a nerve of special sense. It can communicate the impression of sonorous vibrations, but it is not endowed, so far as we know, with any other kind of sensibility.

196. **The Tympanum of the Ear.**—The internal ear communicates with the external atmosphere by a complicated apparatus of movable bones and membranes.

In the outer part of the bony wall of the vestibule is a little oval-shaped perforation, not more than one eighth of an inch long and one sixteenth of an inch wide. This perforation in the bone, which is called the oval "fenestra" or window, is closed by a thin fibrous membrane, which prevents the fluid of the vestibule from escaping. The name given to this opening is a very appropriate one; for the perforation in the bone is really a kind of window, and the fibrous membrane is the sash which closes it. As the light comes into a room through the glass pane of a window, so sounds enter the vestibule through the membrane of the oval fenestra.

Immediately outside the wall of the vestibule, but still within the substance of the petrous bone, is an irregularly shaped cavity, much more spacious than the vestibule itself. At rather less than a quarter of an inch distance from the membrane of the oval fenestra, the mouth of this cavity is closed by another membrane stretched tightly across its diameter, and at-

tached, all around, to the edges of its bony walls. This outer membrane is called the "Membrane of the Tympanum," and the cavity which it incloses is called the "Tympanum," or *Drum* of the ear.

This name is also well chosen; for the exterior of the membrane of the tympanum is in contact with the atmosphere, and the sonorous vibrations of the air beat upon it, like the sticks upon the head of a drum.

197. **Chain of Bones.**—But the sounds are transmitted from the membrane of the tympanum to the membrane of the oval fenestra by a curious chain of bones stretched from one to the other. These bones are three in number, and are named, from striking resemblances in their form, respectively the "mallet," the "anvil," and the "stirrup." The mallet is attached to the membrane of the tympanum, the anvil is articulated with it by a movable joint, and the stirrup is also articulated with the anvil by its point or narrow end, while by its oval base or foot-piece it is attached to the membrane of the oval fenestra (Fig. 64).

It is easy to see, therefore, how the vibrations of the atmosphere, striking upon the membrane of the tympanum, will be transmitted by the chain of bones to the membrane of the oval fenestra, and thus reach the fluid of the labyrinth, to be finally received by the expansions of the auditory nerve.

198. **Eustachian Tube, and its Function.**—Like other drums, the cavity of the tympanum is itself filled with air, and, like them, it also communicates with the exterior by a side opening. This is very essential; for, in order that a membrane may vibrate freely, the pressure of the air must be equal on both sides. Now the pressure of the external atmosphere, as we know from the

Fig. 64.

Human Auditory Apparatus; showing the external ear, the auditory meatus, the tympanum, Eustachian tube, chain of bones, and labyrinth.

changes of the barometer, varies from time to time; and accordingly it would be sometimes greater and sometimes less than that of the same air confined in a closed cavity. The vibrating power of the membrane would therefore be diminished, and it would be less capable of producing and conducting sound. For this reason a small opening is always made in the side of a drum, and through this opening the air inside and that outside are constantly mingled, and maintained at the same degree of pressure.

There is such an opening in the drum of the ear. From the fore part of the tympanum a narrow canal passes downward and forward, and, after continuing its course in this direction for about an inch and a half, it opens by a rounded orifice at the side and upper part of the pharynx. This canal is called the *Eustachian tube*, from the name of the anatomist who first described

it. By holding the mouth and nose, and forcibly pressing the air out of the lungs, we can feel it passing through the Eustachian tube, and finally penetrating into the cavity of the tympanum, which becomes distended under the increased pressure. The tympanum, however, soon relieves itself after the pressure is taken off, the air escaping again through the same passage by which it entered.

If the Eustachian tube be obstructed by inflammation or swelling of its lining membrane, the hearing soon becomes impaired, from the imperfect vibration of the membrane of the tympanum. It is on this account that a common cold in the head is often accompanied by partial deafness.

199. **Variations in Tension of the Membrane of the Tympanum.**—Like the head of a drum, the membrane of the tympanum may be relaxed or tightened. This is done by the action of three small muscles which arise from the bony parts in the neighborhood, and are inserted into the little bones called the "mallet" and the "stirrup." By their alternate contraction and relaxation they draw these bones backward and forward, and so increase or diminish the tension of the membrane.

200. **External Ear and Auditory Meatus.**—The membrane of the tympanum, as we have already seen, is in contact with the external atmosphere; but it is situated at the bottom of a deep passage or canal, about one inch in length, which penetrates the side of the head from without inward. This canal is the *External auditory meatus.* It is lined with a continuation of the skin, which is, however, very thin and delicate near its bottom. It is defended from the intrusion of insects and other foreign bodies by numerous fine hairs growing

from its surface, and by an adhesive and resinous-like secretion, termed the "ear-wax."

At the outer orifice of the auditory meatus is the *External ear* (Fig. 65). This is an irregular trumpet-

Fig. 65.

External Ear.—1. Helix; 2. Anti-helix; 3. Tragus; 4. Anti-tragus; 5. Concha. The mouth of the auditory meatus is partially visible just behind the tragus.

shaped expansion of cartilage, covered with skin, and folded in various ways so as to make a receptacle for the sounds approaching the ear, which it conducts toward the opening of the auditory meatus. Its outer edge is folded inward round nearly the whole of its circumference, thus forming a curved border, which is called the "helix." Inside and in front of this is another curved ridge, double at its upper end, but terminating in a single extremity below, called the "antihelix." About the middle of the front of the ear is a short ridge-like elevation, called the "tragus," and behind and below it another, somewhat similar, the "anti-

tragus." In front of the curved edge of the anti-helix, and occupying the middle portion of the ear, is a deep, cup-shaped cavity, termed the "concha." At its bottom is the mouth of the auditory meatus, nearly concealed behind the eminence of the tragus.

The external ear, which is loosely connected with the bones, has several muscles attached to it, so arranged as to move it upward, forward, and backward. In the human species these muscles are nearly inactive, and it is only very seldom that we meet with persons who are capable of moving the ears. But in many of the lower animals, such as the dog, horse, deer, rabbit, etc., the muscles of the ear are very active, and its movements consequently are rapid and various. The external organ is also larger and more spreading in these animals, forming a kind of natural ear-trumpet, which they turn in various directions, to catch the faintest indications of sound from a distance.

201. **Appreciation of the Direction of Sounds.**—It is not so easy to distinguish the *direction* of sound as that of light. Indeed, whenever we see the light at all, we necessarily see the direction from which it comes. But it is not so with sounds. We may hear a sound perfectly well, and yet be quite unable to tell from what point it reaches us; as when we hear the chirping of a cricket in a closed room, or the sound of a bell in a thick fog. Usually, however, we can judge of the direction of sounds, by noticing in which ear it is most acutely perceived, and in what way it is reflected by surrounding objects.

202. **Effect of Contrast in Sounds.**—The hearing, like the sight, is more excited by the *Contrast* of impressions than by the impressions themselves. A continu-

ous and uniform sound, like the steady rumbling of carriages, or the monotonous hissing of boiling water, after a time passes unobserved; but when the sound ceases, our attention is excited, and we then notice the silence which follows.

203. **Persistence of Sonorous Impressions — Musical Notes.**—As in the case of the sight, also, an impression upon the ear remains for a very short time after it is produced. This interval has even been measured for the sense of hearing; for it is known that if the same vibration be repeated more rapidly than sixteen times in a second, it ceases to be a succession of distinct impulses, and becomes a continuous humming sound, or a *musical note.* If it be still more rapidly repeated, the note is higher in pitch, and so on. Thus a low note is one in which the vibrations are comparatively slow; a high note is one in which the vibrations are rapid.

Accordingly, there are limits in each direction to the pitch of the high or low notes which are audible to us. If the vibrations be excessively rapid, the tympanum can not transmit them, and the sound becomes too fine to be perceived; if they be slower than sixteen times in a second, we then hear the distinct impulses, but no continuous musical note.

By the sense of hearing, therefore, we appreciate the tone, the force, the pitch, and the direction of sonorous vibrations. By means of the articulate words and expressions of human language, we also acquire ideas and information which are but little inferior in value to those obtained through the sense of sight.

204. **The Sense of Smell — Olfactory Nerves.**—By the sense of smell we receive impressions from substances in a condition of gas or vapor. These vapors rise

from the bodies which produce them, and are diffused through the atmosphere. They then penetrate into the passages of the nostrils, and come in contact with their lining membrane, thus giving us the sensation of smells or *Odors.*

The special nerves of the sense of smell are the *Olfactory nerves.* They originate on each side from the front part of the base of the brain, and then, running straight forward, enlarge into two oval masses, containing gray matter, and situated nearly side by side, just behind the middle of the base of the forehead, and immediately above the cavities of the nose. That part of the floor of the skull upon which these oval masses rest is in the form of a thin plate, and is so perforated with a multitude of little openings that it has received the name of the "cribriform" or "sieve-like" plate. Through these openings an abundance of fine nervous branches pass downward, and, after dividing and reuniting with each other in various directions, are distributed to the lining membrane of the upper part of the nasal passages (Fig. 66).

205. **The Nasal Passages.**—The nasal passages are two high and narrow canals, which extend from the openings of the nostrils in front to the top of the pharynx behind. Through them the air passes to the lungs in respiration when the mouth is closed. They are separated from each other by a thin upright partition, which is situated exactly in the middle line. This partition is composed partly of bone and partly of cartilage. Its front part, which is of cartilage, may be felt between the two nostrils at their entrance.

The inner wall of each nasal passage, which is formed by the partition just described, is smooth and upright.

Fig. 66.

Distribution of Nerves in the Nasal Passages.—1. Olfactory nerve; 2. Nasal branch of fifth pair; 3. Ganglion of Meckel and its nerves.

But its outer wall is made very uneven by three curiously rolled or twisted plates of bone, called, from their form, the *Turbinated Bones*, which project from it into the passage. These bones are placed one above another like so many shelves, and are therefore called the "lower," "middle," and "upper" turbinated bones. They are all covered with the lining membrane of the nose, which follows every where their windings and inequalities, so that its surface is considerably increased in extent.

206. **Different kinds of Sensibility in the Nasal Passages.**—Now the ramifications of the olfactory nerve are distributed to the lining membrane of the upper and middle turbinated bones. It is here, accordingly, that the sense of smell is located. Whenever an odoriferous vapor passes through the nose with the atmosphere, a portion of it rises to the upper part of the nasal passages, and, coming in contact with this por-

tion of the lining membrane, gives us the sensation of its peculiar odor.

The lower part of the nasal passages, on the contrary, have no sense of smell, but are supplied with other nervous fibres. A small branch of the fifth pair of nerves (Fig. 66 [2]) penetrates the side of the nostril high up, and then, running in a curved direction forward, downward, and backward, is distributed to the lining membrane of the lower turbinated bone and the adjacent parts. By this nerve the lower portions of the lining membrane are provided with ordinary sensibility. They can feel the contact of solid bodies, or of sharp and irritating vapors.

Thus the passages of the nose are endowed, in their different parts, with two different kinds of sensibility. In their upper portions, by means of the olfactory nerves, they are provided with the special sensibility of smell, by which we perceive sweet and sour odors, and all the different varieties of *perfume*, which are so easily recognized, but which have received no definite name. In their lower portions, by means of the nasal branch of the fifth pair, they possess the power of ordinary sensibility, by which we perceive the contact of *sharp* and *pungent* vapors, such as that of hartshorn or mustard. These pungent vapors are quite different in their nature from those which have an odoriferous quality. For the true odors, such as those of different flowers and the like, can only be perceived by the nose. But the pungent vapors are also irritating to other lining membranes, such as those of the eyes and mouth, and even to the skin, if kept in contact with it long enough; only the lining membrane of the nose is more sensitive to them than the rest.

Very often a real odor and a pungent vapor are exhaled together from the same substance; as, for example, from mustard, from vinegar, or from Cologne water. But, in these cases, the odoriferous quality is always perceived by the upper part of the nasal passages, and the pungent or irritating quality by their lower part.

207. **Sympathetic Nerves in the Nasal Passages.**—The organ of smell is also supplied with nerves belonging to the sympathetic system. Immediately behind the posterior boundary of the nasal passages, and beneath the floor of the skull, is a small swelling of gray nervous matter, called, from the name of its discoverer, the *Ganglion of Meckel* (Fig. 66 [3]). This ganglion is connected by slender filaments with the sympathetic plexus of the great blood-vessels of the head, and also with branches of the sensitive and motor cranial nerves. Its fibres are sent to the lining membrane of the nose, and also to the small muscles which lift the hanging palate, and thus guard the posterior opening of the nasal passages.

208. **Usefulness of the Sense of Smell.**—The sense of smell is one of those which are possessed in much greater perfection by some of the lower animals than by man. In the dog, the horse, the sheep, the deer, and many others, the nasal passages are much higher and deeper, the turbinated bones more extensively convoluted, and the olfactory nerves themselves much larger and more sensitive. These animals can therefore distinguish odors which are entirely imperceptible to us. They can perceive the odors of other animals while at a distance and out of sight. The dog can even distinguish between the odors of different persons, and will follow the track of his master through a crowd of other

passers-by. Some animals, when irritated, give out strong and offensive odors, which excite the fear or disgust of their enemies, and accordingly serve them as means of defense. Many vapors which are dangerous to the health of the human species, and most kinds of putrescent and unwholesome food, are also accompanied by a disagreeable odor, which leads us to avoid them, and thus to escape their injurious effects.

209. **The Sense of Taste—Gustatory Nerve.**—The sensibility to taste is located in the tongue. As we have already said, this is a muscular organ, covered, upon its upper surface, its edges, and part of its under surface, with a lining membrane. Over the whole middle and front part of the tongue this membrane is supplied with sensibility by a branch of the fifth pair of nerves; and, as this branch is that by which the corresponding portions of the tongue exercise the sense of taste, it has received the name of the *Gustatory nerve.*

210. **Distribution of the Gustatory Nerve upon the Tongue.**—On the under surface of the tongue its lining membrane is thin and smooth, and allows the blood-vessels to be easily seen through its transparent substance. But upon the upper surface of the organ this membrane is thickly set with a multitude of fine, thread-like prominences, something like the villi of the alimentary canal, which give it an opaque and velvety appearance. These prominences are termed the *Papillæ* of the tongue. As the gustatory nerve branches and subdivides in the substance of the lining membrane, it sends minute ramifications into the papillæ, which penetrate them from below upward, and terminate near their free extremities (Fig. 67). Thus the upper surface of the tongue is covered with a minute distribu-

Fig. 67.

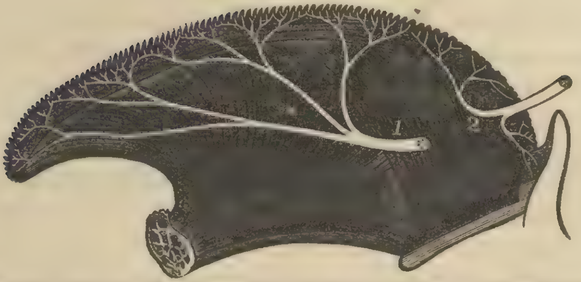


Diagram of Tongue, with its sensitive nerves and papillæ.—1. Lingual branch of fifth pair, or gustatory nerve; 2. Glosso-pharyngeal nerve.

tion of nervous filaments, through which it receives the impressions of taste.

211. **Requisite Conditions for the Sense of Taste.**—The sense of taste differs from the other special senses, in the first place, because it requires the *actual contact* of the substance to be tasted with the lining membrane of the organ. We can not perceive tastes as we can odors and sounds from a distance. The substance must be introduced into the mouth, and placed upon the surface of the tongue, before we can distinguish its flavor. Beside this, it must also be in the *fluid form*, or be already in solution in some other liquid. A substance which is hard and insoluble has no taste. If we place upon the tongue a piece of dry salt or sugar, we do not perceive its flavor until a part of it has been dissolved in the fluids of the mouth. Then these fluids are absorbed by the papillæ of the tongue, and thus, coming in contact with their nervous filaments, communicate to us the sensation of taste.

It is on this account that the sense of taste is so much facilitated by the *movements* of the tongue in mastication and swallowing. For these movements, by hasten-

ing the solution of solid substances, and by constantly bringing fresh portions of the fluid into contact with the tongue, favor the absorption of the liquids, and enable them to penetrate the papillæ in greater quantity. Food, therefore, which has been hastily masticated, is imperfectly tasted; and in this way injurious substances may pass into the stomach unnoticed, which should have been detected and stopped in mastication.

212. **Uses of the Sense of Taste.**—The sense of taste, accordingly, as well as that of smell, is a means of distinguishing between proper and unwholesome articles of food. Some substances, when taken into the mouth, are found to be repulsive, and are therefore rejected. In many of the lower animals, however, this office is performed exclusively by the sense of smell. The dog, for example, very seldom tastes any thing before eating it. He touches it with the point of his nose, and then either swallows it with avidity or refuses it altogether. It is because in him the sense of smell is more delicate than that of taste, while in man the sense of taste is more delicate than that of smell.

The sense of taste is also useful in exciting the flow of the saliva and other secretions, by which the food is prepared for the digestive process. Substances which are destitute of flavor offer no stimulus to the salivary glands or to the muscles of mastication, and this process is therefore either neglected or slowly and laboriously performed. But substances which have a healthy and agreeable taste excite the natural actions of secretion and mastication, so that the movements go on almost involuntarily, and the food receives its due preparation in the mouth.

213. **The Sense of Taste associated with the Sense of**

Touch.—Another peculiarity of this sense is that the special nerve of taste *is also a nerve of ordinary sensibility.* We have already seen that the same parts of the tongue which possess the sense of taste have also the sense of touch developed to a remarkable degree; and these two properties are both supplied by the branch of the fifth pair which is distributed to this organ. In the nasal passages, the special sense of smell and the power of ordinary sensibility reside in different portions of the lining membrane; but in the tongue, the special sense of taste and ordinary sensibility are exercised by the same parts, and reside in the filaments of the same nerve.

Accordingly, two kinds of qualities are distinguished by this organ in different substances. The first are the qualities of *taste* proper, which we call "sweet," "sour," "salt," "bitter," and the like; these are perceived by the special sensibility of the gustatory nerve, and belong only to the tongue. The second are the qualities which depend upon the *consistency*, *mildness*, or *pungency* of the substance, such as a "watery," "viscid," "oily," "sharp," or "burning" taste. These are perceived by the ordinary sensibility of the tongue, and may also be distinguished, though in a less degree, by the surface of the skin or by the other lining membranes.

There are certain substances which have at the same time a well-marked and usually agreeable taste and a penetrating, fragrant odor; such as coffee, peppermint, ginger, and the spices generally. These are called *Aromatic* substances. Many of them have also more or less pungency mingled with their other qualities. They are employed either alone or for the purpose of flavoring other articles of food.

214. **Posterior Portion of the Tongue.**—That part of the tongue which is situated far back in the mouth is smoother than the rest, and is provided with mucous follicles instead of papillæ. This portion of the organ is also supplied with a different nerve, which, from its being distributed partly to the tongue and partly to the pharynx, is called the *Glosso-pharyngeal* nerve (Fig. 67 [2]). This nerve also possesses the sensibility of taste, which is developed to a perceptible degree, especially for aromatic substances, in the back part of the tongue and the surrounding portions of the throat. The sensations of taste, however, are not especially excited in these situations until just at the moment of swallowing. At that time the food, carried back by the tongue, comes in contact with the lining membrane of these parts, and, being also compressed by the action of the muscles, calls into activity the sensibility of the glosso-pharyngeal nerve. Once past this situation, however, it is beyond the region of the special sense, and in the œsophagus and the stomach its taste is no longer perceived.

QUESTIONS FOR CHAPTER XVII.

1. What are meant by the *special senses?*
2. What is the peculiarity of a *nerve of special sense?*
3. What is the structure of an *organ of special sense?*
4. What is the special nerve of the *sense of sight?*
5. From what ganglia do the optic nerves originate?
6. What is the course and termination of the optic nerves?
7. What is the *decussation of the optic nerves?*
8. How are the two optic tubercles connected with each other?
9. How are the two eyeballs connected with each other?
10. Are the eyes to be regarded as two distinct organs or as one double organ?
11. How do the optic nerves terminate in the interior of the eyeballs?

12. What is the property or function of the optic nerves?

13. What is the effect of injury or division of the optic nerves?

14. What reflex action takes place through the optic tubercles?

15. What do you mean by the *sensibility of the pupil?*

16. Is this sensibility necessarily accompanied by consciousness?

17. What is the special *organ* of sight?

18. In what cavity is the eyeball situated?

19. What is the form of the eyeball?

20. What is the *sclerotic coat* of the eyeball? What is its structure and consistency?

21. What is the *cornea*, and where is it situated?

22. How does the cornea differ from the sclerotic?

23. Through what part does the light enter the cavity of the eyeball?

24. What is the *choroid coat* of the eye? What is its color and consistency?

25. What is the use of the choroid coat?

26. What is the situation and structure of the *retina?*

27. What is the function of the retina?

28. Does the retina possess ordinary sensibility?

29. To what kind of impressions is it sensitive?

30. What is the effect of injury or disease of the retina?

31. What is the *vitreous body* of the eye, and why so called?

32. What is its use?

33. What is the situation and form of the *crystalline lens?*

34. How is the lens held in its place?

35. What is the use of the crystalline lens?

36. What is the *focus* of a lens?

37. Where is the focus of the crystalline lens in the eye?

38. What is the *iris?* and why so called?

39. What is the *pupil?*

40. Of what tissue is the iris composed?

41. What two sets of muscular fibres does it contain?

42. What is the action of the diverging fibres?

43. What is the action of the circular fibres?

44. What are the movements of the pupil on passing from the dark into the light? from the light into the dark?

45. What ganglion and nerves of the sympathetic system take part in the reflex movements of the pupil?

46. What is the situation of the *ophthalmic ganglion?*

47. What is the course and termination of the *ciliary nerves?*

48. What is the *aqueous humor* of the eye?

49. What is the *field of vision?*

50. In what part of the field of vision can objects be seen *distinctly?*

51. What is the *line of distinct vision?*

52. Why are objects outside this line seen indistinctly?

53. How do we compensate for this in using the eyes?

54. Why can an object be seen distinctly with both eyes only at a certain distance?

55. Why do objects appear single, though seen with two eyes?

56. How can we see an object indistinctly, and, at the same time, double?

57. Can we see all parts of a landscape distinctly at the same time, and why?

58. How do we judge of the *distance* of various objects?

59. How is the appearance of *solidity* or *projection* produced in vision with two eyes?

60. Can a single flat picture ever represent a solid object so as to deceive the eye, and why?

61. What is a *stereoscope*, and how does it produce the appearance of solidity?

62. What is the effect of *contrast* on visual impressions?

63. What colors make the strongest contrast?

64. How can one color appear different by contrast with another?

65. What is the effect of mixing two different colors? blue and yellow? yellow and red? red and blue? black and white?

66. Do the impressions of sight disappear immediately, or remain for a short time? Give an instance.

67. What is the *thaumatrope*, and how is its effect produced?

68. How may the impressions of sight be produced without visible objects?

69. How are the *movements* of the eyeball provided for?

70. What are the direction and attachments of the *straight muscles of the eyeball?* What is their action?

71. What are the direction and attachments of the *upper oblique muscle of the eyeball?*

72. Why is it called the *trochlearis* muscle?

73. What are the direction and attachments of the *lower oblique muscle of the eyeball?*

74. What is the action of the two oblique muscles of the eyeball?

75. What are the two uses of the movements of the eyeball?

76. How is the eyeball protected from external injury?

77. What is the structure of the *eyelids?*

78. Which is the larger and more movable of the two?

79. How is it raised and lowered in front of the eye?

80. What is the *conjunctiva?*

81. How is the conjunctiva kept moist and transparent?

82. In what gland are the tears produced, and where is it situated?

83. Where do the ducts of the lachrymal gland open upon the conjunctiva?

84. How are the tears spread over the surface of the conjunctiva?

85. By what muscle is the act of winking performed?

86. What is the use of the act of winking, and how would the eye suffer if it were not performed?

87. Is the act of winking voluntary or involuntary?

88. Why does it usually pass unnoticed?

89. How are the tears prevented from running over the edges of the eyelids?

90. By what glands is the sebaceous secretion of the eyelids produced?

91. How is the act of *weeping* produced?

92. How are the tears conveyed away from the surface of the eyeball, and where are they finally discharged?

93. What are the *eyelashes*, and what is their use?

94. Is the conjunctiva sensitive or insensible?

95. How does its sensibility serve to protect the eye from injury?

96. How may the sight be injured by excessive use? by too brilliant light? by continued examination of small objects?

97. By reading with insufficient light?

98. What is the best kind of light for reading or studying?

99. What is the worst?

100. How is *sound* produced?

101. How is the vibration of the *atmosphere* necessary to our hearing sounds?

102. What is the definition of the sense of hearing?

103. What is the *special nerve* of the sense of hearing?

104. What is the origin and course of the auditory nerve?

105. What is the situation of the *petrous* bone, and why so called?

106. What is the *labyrinth*, and why so called?

107. What is the shape and name of the first portion of the labyrinth?

108. What are the *semicircular canals*, and how do they differ from each other in their position?

109. What is contained in the cavities of the vestibule and the semicircular canals?

110. Upon what are the fibres of the auditory nerve distributed in the vestibule and semicircular canals?

111. What is the name of the remaining portion of the labyrinth, and why so called?

112. Upon what are the fibres of the auditory nerve distributed in the cochlea?

113. What parts are included in the *internal ear?*

114. What kind of sensibility resides in the auditory nerve?

115. What is the opening called the *oval fenestra*, and where is it situated?

116. By what is the oval fenestra closed?

117. What is the use of the oval fenestra?

118. Where is the cavity of the *tympanum* or *drum* of the ear?

119. What is the *membrane of the tympanum?*

120. How are sounds transmitted from the tympanum to the oval fenestra?

121. What are the three bones of the chain, and why so called?

122. Which of them is attached to the membrane of the tympanum, and which to the membrane of the oval fenestra?

123. What is contained in the cavity of the tympanum beside the chain of bones?

124. Why must a drum always communicate with the external atmosphere?

125. By what opening does the tympanum of the ear communicate with the exterior, and where is it situated?

126. What effect is produced by obstruction of the Eustachian tube?

127. How is the membrane of the tympanum relaxed and tightened?

128. What is the *external auditory meatus?*

129. How is it defended from the entrance of foreign bodies?

130. What is the general form and structure of the *external ear?*

131. What is its function?

132. What is the *helix?* the *anti-helix?* the *tragus?* the *anti-tragus?* the *concha?*

133. In which of the lower animals are the external ears *movable?*

134. What is the use of these movements?

135. How do we judge of the *direction* of sounds?

136. How is the sense of hearing affected by *contrast* of sounds?

137. What is the effect of the same sound long continued?

138. Are the impressions of sound immediately evanescent, or do they remain for a certain period?

139. How is a *musical note* produced?

140. What must be the frequency of the vibrations in order to produce a continuous note?

141. What is the difference in the rapidity of the vibrations between a high and a low note?

142. What do we learn by the sense of hearing?

143. What kind of impressions are perceived by the *sense of smell?*

144. What are the *special nerves* of the sense of smell?

145. What is the origin, course, and distribution of the olfactory nerves?

146. What is the form and direction of the *nasal passages?*

147. With what do they communicate behind?

148. How are they separated from each other?

149. What are the *turbinated bones*, and why so called?

150. How many turbinated bones are there in each nasal passage, and how are they distinguished from each other?

151. With what are the turbinated bones covered?

152. Upon what part are the olfactory nerves distributed?

153. In what part of the nasal passages does the sense of *smell* reside, and in what part the sense of *touch?*

154. What sensitive nerve is distributed to the lower part of the nasal passages?

155. What is the difference between *odors* and *pungent vapors?*

156. Name examples of each.

157. What ganglion of the sympathetic system is connected with the organ of smell?

158. Where is the ganglion of Meckel situated? With what other nerves is it connected, and where are its nerves distributed?

159. In what animals is the sense of smell more acute than in man, and why?

160. How does the sense of smell serve as a protection—in animals? in man?

161. What is the organ of *taste?*

162. What is the principal *nerve* of the sense of taste?

163. To what part of the tongue is the gustatory nerve distributed?

164. What are the *papillæ* of the tongue, and where situated?

165. What are contained in the papillæ of the tongue?

166. What two conditions are essential to the sense of taste?

167. How do the *movements* of the tongue assist in the sense of taste?

168. What is the use of the sense of taste?

169. What is the comparative delicacy of taste and smell—in the lower animals? in man?

170. How does the sense of taste assist mastication and digestion?

171. What other sensibility resides in the tongue beside that of taste?

172. What is the difference between the qualities of *taste*, and those of pungency and the like? Give examples of both.

173. What is an *aromatic* substance? Give examples.

174. How does the *back part* of the tongue differ from the front part?

175. By what nerve is it supplied?

176. What kind of sensibility is especially developed in the back part of the tongue?

177. At what point does the sense of taste terminate?

Section IV.

DEVELOPMENT.

CHAPTER XVIII.

DEVELOPMENT.

Definition of Development.—Newly-born Infant—its Weight—condition of its Skeleton.—Ossification of the Skeleton.—Spinal Column.—Skull.—Fontanelles.—Pelvis.—Long Bones.—Respiration of the Infant—its Digestion and Nutrition—its Nervous System.—Reflex Actions.—Formation of the Teeth.—First Set.—Childhood.—Muscular System of the Child.—Nervous and Mental Functions.—Preponderance of the Instincts.—Formation of new Set of Teeth.—Youth.—Continued Ossification of the Skeleton.—Union of the Bones.—Completion of Development.

215. **The Process of Development.**—The newly-born infant is in a very different condition from that of a child or a grown-up person. It is feeble, and entirely dependent on the care of others for its existence almost from day to day. Many of its organs are very imperfect, and the form and proportions of its whole body are different from those which it will afterward acquire. The growth of the infant into the child, and of the child into the adult, is not therefore simply an increase in size. It is a series of changes in the condition and structure of its various parts, by which it passes through as many different stages or epochs of existence. This series of changes, by which the bodily frame is brought at last to the adult condition, is called its *Development.*

216. **General Condition of the Infant at Birth.**—The weight of the newly-born infant is between six and seven pounds. The head and arms are larger, and the pelvis and lower extremities smaller, in proportion to

each other, than in the adult. The legs are curved inward at their lower part, so that the soles of the feet are not horizontal, but look obliquely inward toward each other. Even if the infant were strong enough, therefore, it could not walk, since the feet would not rest upon the ground by their soles, but by their outer edges. Both arms and legs, also, are habitually curled upward and forward over the chest and abdomen, and are not easily straightened.

217. **Condition of the Skeleton.**—The skeleton at birth is soft and yielding, being composed, to a great extent, of cartilage. Some of the bones have already begun to show themselves in the interior of these cartilages ; but they are nearly all small and delicate, and many of them are still cartilaginous throughout. The bony parts, however, continue to enlarge at the expense of the cartilage, until, at the end of some years after birth, the whole has been converted into the tissue of bone. This gradual change of the parts from the cartilaginous to the bony condition is called the *Ossification* of the skeleton.

218. **The Spinal Column.** — At birth each bone of the spinal column consists of three separate pieces, viz., one in front of the spinal cord, and one on each side behind it. These pieces are, of course, connected with each other by cartilage, and thus envelop the spinal cord with a series of soft and elastic rings.

219. **The Skull.**—The bones of the skull are very thin and flexible, and their edges are not yet united with each other. The skull of the infant, therefore, is not a firm and solid case, like that of the adult, but rather an elastic bag, formed of separate plates, held together by the skin and fibrous membranes. A remarkable pecul-

iarity of the skull at this time is that there are two openings in its bony parts, one at the back and one on the top of the head, where the brain is only covered by the skin and other soft tissues. These openings are called the *Fontanelles*, because we can feel the pulsations of the brain through them, like the bubbling of water in a fountain.

220. **Formation of the Fontanelles.**—The fontanelles are formed in this manner. The ossification of the bones on the sides and upper part of the skull begins by a rounded spot in the middle of each one. From this spot the ossification extends outward in every direction, thus gradually approaching the edges of the bone. When two adjacent bones meet, therefore, there will be a line where their edges are in contact with each other, but have not yet united; but when more than two bones meet in this way, there will be an empty space between them at their point of junction. Thus, if you lay down three coins upon the table with their edges touching each other, there will be a three-sided space in the middle between them; if you lay down four coins in the same manner, the space between them will be four-sided. Now at the back part of the head there is a spot where three bones come together in this way, leaving a small three-sided opening between them: this is called the "posterior fontanelle." On the top of the head four bones come together, leaving between them a large four-sided opening: this is called the "superior fontanelle." The fontanelles gradually diminish in size, owing to the growth of the bony parts around them, and are completely closed at the age of four years after birth.

221. **The Pelvis and Limbs.**—The pelvis is also, at first,

in great measure cartilaginous, being composed, on each side, of three separate pieces of bone, with layers of cartilage between them. These three bones of the pelvis meet, in a kind of triangular union, in the cavity of the hip-joint.

The bones of the arms and legs, at the time of birth, are only ossified in their middle portion, their two ends being still cartilaginous. The wrist is altogether cartilaginous, and the ankle nearly so. Owing to this preponderance of cartilage, the bones are soft and flexible. It is evident, accordingly, that the skeleton of the infant is not yet fit to sustain the weight of the body, nor to resist a strong muscular action.

222. **Organs of Respiration.**—The function of respiration is very imperfectly performed for some time after birth. The lungs do not fully expand at once, and the air only penetrates into all the vesicles of their deeper parts after an interval of several days. To compensate for this, however, the skin is very delicate, transparent, ruddy, and vascular; and respiration, no doubt, takes place through it as well as through the lungs. Accordingly, the infant is more sensitive to cold than an older person, and the warmth of the body needs to be more carefully preserved by soft clothing and artificial heat.

223. **Organs of Nutrition.**—On the other hand, the functions of digestion and nutrition are exceedingly active. But the infant takes only one kind of food, viz., the milk of the mother; and this fluid, as we have seen in a former chapter, contains all the materials necessary for the nourishment of its body. This food must be given in abundance, but at short intervals; for the stomach can not digest a large quantity at a time, and therefore requires it to be more frequently supplied.

224. **Nervous System.**—The nervous system of the young infant is in a peculiar condition. The special senses, the sight, hearing, smell, and taste, are all imperfect, and comparatively inactive. The consciousness and the will are also feeble, and the intelligence is still dormant. The involuntary and reflex actions, however, are highly developed. The movements of the arms and legs, and the various intonations of the voice, are nearly all of a reflex nature, mostly performed by the action of the spinal cord and medulla oblongata. A large portion of the time is spent in sleep. For it is especially during sleep that the functions of nutrition go on with the greatest activity and the tissues are consolidated by the assimilation of the food. The business of the young infant is to feed and grow, and the action of his nervous system is almost entirely subservient to these two functions. He does not understand articulate language, nor notice its sounds sufficiently to remember or repeat them; and he is therefore called an infant, from the Latin word *infans*, which signifies "not speaking."

225. **Appearance of the Teeth.**—Within the first year after birth the *Teeth* begin to show themselves. For the infant, after a time, has acquired so much strength, and the different parts of his body are so fully developed, that he will soon need food of a more solid form and greater variety. He will then require the organs of mastication, and these organs, accordingly, begin to be developed in advance. The incisor teeth are the first to emerge from the gums in the seventh and eighth months. At the end of a year there is one molar tooth on each side of each jaw, making four in all. At a year and a half the four canine teeth appear; and at two

years of age four other molar teeth are added to the preceding. There are then twenty teeth in all, or ten in each jaw, viz., four incisors, two canines, and four molars. They are all small, however, and are adapted to the size and form of the jaws at this age. They are called the *Milk teeth*, because they appear while the infant is still fed principally upon milk.

226. **Transition from Infancy to Childhood.**—At the age of two years the infant has so far increased in muscular strength, and his skeleton has become so firm, that he can walk without assistance, and no longer requires the constant care and attendance of others. His teeth and digestive organs enable him to consume a variety of solid and nutritious food. His nervous system has also emerged from its condition of lethargy, and his senses are actively engrossed with surrounding objects. Finally, he has learned to understand and to speak articulate language. He is then no longer an infant, but a child.

227. **Growth of the Muscles during Childhood.**—The term of childhood extends from the age of two years to that of thirteen. During this period the muscular system becomes actively developed; and the skeleton, though still imperfectly consolidated, is sufficiently strong to perform its function with the light weight of the body at this age. The child accordingly takes the greatest enjoyment in the active sports, in which he feels the increasing vigor of his muscles, and the freedom and agility of his limbs. Nothing is more appropriate or more useful at this age; for the frame is now being developed, not by passive feeding and care, as was the case in the infant, but in great measure by the natural and active exercise of its own powers.

228. **Development of the Senses.**—The nervous system acquires an equal development, and the mental qualities at the same time become more active. The child learns rapidly, and is interested in every thing around him. But it is principally in the cultivation of the *Senses* that he gains information. He learns the names and the forms of things, the meaning of words, and the employment of all the objects in common use. This knowledge is not acquired by steady mental application, which would be injurious to him at this age, but by the exercise of the senses, which are now, for the first time, endowed with their full vigor and sensibility.

229. **Activity of the Instincts.**—The nervous system of the child is also distinguished by the active preponderance of the *Instincts* and the *Impulses.* It is by these that his actions are guided; and therefore, though his movements and acts are all voluntary in their nature, they do not, for the most part, depend upon the reasoning faculties, which are still imperfectly developed. Accordingly, the child is to be governed principally through his instincts and feelings, which should be guided in a healthy and natural direction. The dominion of reason comes at a later period, when the entire development of the nervous system is complete.

230. **Change of Dentition.**—During the period of childhood a remarkable change takes place in the organs of mastication. It consists in the entire removal of the first set of teeth, and the appearance of a second or permanent set, which take their places. This change is effected in the following manner.

At the time of birth, although no teeth are to be seen, there is still a complete set already existing in the jaw. These teeth, however, are not yet ossified, but consist

each of a soft vascular prominence, or papilla, called the *pulp* of the tooth, which is inclosed in a little sac or follicle, and buried deeply in the substance of the jaw. The upper surface of the pulp is covered with a very thin layer or crust of calcareous tissue, which is the commencement of the hard substance of the future tooth. As the pulp of each tooth increases in size, more and more of it becomes ossified, until at last it is ready to emerge from the gum. The teeth then make their appearance in the order which we have described above, thus completing the first set at the end of two years.

But, at the same time, there is another set of similar follicles and tooth-pulps, formed deep in the substance of the jaw, behind those of the first set. These tooth-pulps, however, are very small, and remain dormant, or grow very slowly during the first years of childhood. But about the sixth year they begin to grow more rapidly. Their ossification also goes on with a corresponding activity, and they then begin to push their way toward the surface of the gum. They thus press upon the others, which yield before them, grow loose, and are finally detached. The first set are thus thrown off from their attachments to the jaw, and disappear. This process is called the *Shedding of the milk teeth.*

As the milk teeth are thus removed, they are replaced by the new teeth of the second set, which soon afterward emerge behind them. The teeth of the second set, however, are different from those of the first. They are harder in texture, and some of them are of larger size. They are also more numerous; for, instead of the twenty teeth which composed the first set, there are now thirty-two. This is because there are at this time three new permanent molars added on each side

of each jaw. The jaw itself also increases in size, to accommodate the larger number of teeth which it contains.

The shedding of the milk teeth begins about the age of seven years. During the seventh and eighth years the incisor teeth are changed, and replaced by those of the permanent set. In the ninth and tenth years the two molar milk teeth are thrown off, and replaced in a similar way by the two anterior permanent molars; and in the twelfth year the canine teeth are changed. The first of the three posterior molar teeth has already made its appearance; and in the thirteenth year the second emerges from the jaw. There remains only one, viz., the third posterior molar, or the last tooth in the back part of the jaw on each side. These teeth only appear from the seventeenth to the twenty-first year, and are therefore known by the name of the "wisdom teeth." They complete the development of the masticatory apparatus.

With the exception, therefore, of the third posterior molar or "wisdom" tooth, the entire change from the first to the permanent set is accomplished during the period of childhood.

231. **Transition from Childhood to Youth.**—To the period of childhood succeeds that of Youth. During this epoch the consolidation of the skeleton goes on, and is particularly distinguished by the union of the different parts of the bones with each other. Thus the three bones of the pelvis on each side become united into one from the thirteenth to the fifteenth year; and the consolidation of the ends of the long bones of the arms and legs with their middle portions is effected generally from the fifteenth to the twentieth year. At the same

time, these bones assume the form and dimensions which are characteristic of the adult, and the posture and movements acquire more firmness and solidity. The general development of the skeleton and limbs may be said to be terminated at the age of twenty years.

232. **Completion of the Process of Development.**—During the period of youth the nervous system becomes fully developed, and the mental powers are exercised with greater freedom than before. The youth begins to prepare for the active occupations of life by regular and continuous study; and the commencing supremacy of the reasoning faculties enables him to understand, not only the sensible qualities of surrounding objects, but their relations to each other, and the manner in which he may employ them for useful purposes. The body also acquires at this time a different appearance, and the proportions of its various parts are altered. The limbs are stronger, and the joints comparatively smaller than in the child; and many of the internal organs become altered in their size and weight, as compared with that of the whole body. Thus both the anatomical structure and the physiological actions of the bodily frame, having passed successively through their different stages of preparation and growth, arrive at last at the fully developed and adult condition.

QUESTIONS FOR CHAPTER XVIII.

1. What is meant by the *development* of the body?
2. What is the weight of the newly-born infant?
3. How do the proportions of its body differ from those of the adult?
4. What is the position and form of the arms and legs?
5. What is the condition of the *skeleton* at birth?
6. What is meant by the *ossification* of the skeleton?

7. What is the condition of the *spinal column* at birth? of the *skull?*

8. What are the *fontanelles?* and how are they formed?

9. What is the shape and situation of the *posterior* fontanelle?

10. What is the shape and situation of the *superior* fontanelle?

11. At what age are the fontanelles completely closed?

12. Of how many separate pieces is the *pelvis* composed at the time of birth?

13. What is the condition of the bones of the arms and legs? of the wrist? of the ankle?

14. Why is the skeleton of the infant unfit to sustain the weight of the body?

15. What is the state of *respiration* at birth?

16. How long does it require for the lungs to be completely filled with air?

17. How is this deficiency compensated for in the young infant?

18. Why is the infant more sensitive to cold than the adult?

19. What is the state of *digestion* and *nutrition* in the infant?

20. What is the proper food of the infant?

21. Why should it be given at short intervals?

22. What is the state of the *special senses* in the infant? of *consciousness?* of the *intelligence?*

23. What kind of *movements* are those mostly performed by the infant?

24. Why does the infant require a large amount of *sleep?*

25. Why is the newly-born child termed an *infant?*

26. At what time do the *teeth* begin to appear?

27. When do the *incisors* show themselves? the first *molars?* the *canines?* the remaining molars?

28. How many teeth, in all, form the first set?

29. Why are they called *milk teeth?*

30. What is the difference between an *infant* and a *child?*

31. What is the extent of the period of childhood?

32. What changes take place during childhood in the skeleton and the muscles?

33. Why should the child pass much of his time in active sports?

34. What part of the nervous system is most fully developed during childhood?

35. How does the child learn most easily and profitably?

36. What nervous actions are most fully developed in the child?

37. What change takes place during childhood in the organs of mastication?

38. What is the condition of the first set of teeth at the time of birth?

39. What is the *pulp* of the tooth?

40. In what is it contained?

41. How is the pulp converted into the hard tooth?

42. At what time is the first set of teeth completely formed?

43. When and where are the *second set* of teeth formed?

44. How long do they remain dormant?

45. When do they begin to grow and become ossified?

46. What effect does this have on the teeth of the first set?

47. What becomes of the teeth of the first set?

48. How do the teeth of the second set differ from those of the first?

49. How many teeth are there in the second set?

50. What change takes place in the *jaw* at this time? and why?

51. When does the shedding of the milk teeth begin?

52. Which are the first teeth to be changed?

53. When are the molar teeth changed? the canine teeth?

54. When does the *first* posterior molar show itself? the second? the third?

55. Why is the third posterior molar called the *wisdom tooth?*

56. What is the next period to that of childhood?

57. What especial changes take place in the skeleton during the period of youth?

58. When are the three bones of the *pelvis* united?

59. When does the consolidation of the long bones of the arms and legs take place?

60. At what age is the general development of the body complete?

GLOSSARY.

Abdomen (Latin *abdo*, to hide). The lower part of the body situated beneath the level of the diaphragm; the belly; so called because the abdominal organs are concealed or hidden in it.

Absorption (L. *ab*, from, and *sorbeo*, to suck up). The imbibition of a fluid by an animal membrane or tissue.

Adipose Tissue. The fat.

Air Vesicle. A minute vesicle containing air, which goes to make up the tissue of the lungs.

Albumen (L. *albus*, white). An animal substance which coagulates when heated; so called because it turns white in coagulating. Hence, "white of egg."

Albuminose. An animal substance, not coagulable by heat, produced in digestion by the action of the gastric juice on albuminous substances.

Albuminous Matter. Any animal substance resembling albumen.

Alimentary Canal. A long tube, of varying form and size in its different parts, in which the preparation and digestion of the food, or "aliment," is performed. It comprises the mouth, the pharynx, the œsophagus, the stomach, and the small and large intestine.

Alkali (Arabic *Al Kali*, the soda-plant). A name given to certain chemical substances which have the power of combining with acids in such a way as to neutralize their acidity; such as soda, potash, and the like.

Alkaline Fluid. A fluid containing a perceptible quantity of an alkali.

Anatomy (Greek *ἀνὰ*, *ana*, through, and *τομή*, *tomee*, a cutting). Literally, "dissection." The study of the different parts and structure of the body.

Anti-helix. The curved ridge in the external ear, situated inside and in front of the helix.

Anti-tragus. A ridge-like elevation in the external ear, situated behind and below the tragus.

Anvil. The middle one of the three small bones in the tympanum of the ear, resembling an anvil in shape.

Aqueous Humor (L. *aqua*, water, and *humor*, a liquid). A thin watery fluid situated in the eye, between the front of the iris and the inner surface of the cornea.

Apparatus. A collection of different organs, which are associated in the performance of the same function.

Aorta. The great artery which passes off from the left ventricle of the heart, and which is the main trunk of the whole arterial system.

ARCH OF THE AORTA. The semicircular bend of the aorta, in the upper part of the chest, from which the main arteries to the arms and head are given off.

ARTERIAL Blood. The bright red blood contained in the left side of the heart and the arteries of the general circulation.

ARTERY (Gr. *ἀὴρ*, *aer*, air, and *τηρέω*, *tereo*, to keep). A vessel conveying the blood from the heart outward to the organs; so called because the ancients thought these vessels contained air.

ARYTENOID Cartilages (Gr. *ἀρυταινα*, *arutaina*, a kind of water-jug or pitcher). Two movable cartilages situated in the larynx, to which the vocal chords are attached posteriorly; so called from a supposed resemblance in their form to that of a water-pitcher.

ASSIMILATION. The process by which the ingredients of the food are converted into those of the tissues.

AUDITORY Nerve (L. *audio*, to hear). The special nerve of the sense of hearing.

AURICLE (L. *auricula*, the outer ear). The smaller and thinner chamber of the heart on each side, which receives the blood directly from the veins; so called from a fancied resemblance in shape to a dog's ear.

BICEPS FLEXOR (L.). A muscle situated upon the front part of the arm above the elbow, which serves to bend the elbow-joint.

BILE. The secretion produced by the liver.

BILIARY DUCT. A duct which conveys the bile from the liver to the intestine.

BILIARY SALTS. Two peculiar substances, formed by the combination of certain animal matters with soda, which are the most important ingredients of the bile.

BLOOD GLOBULES. Minute rounded and flattened semi-fluid bodies of a red color, which are found in great abundance in the blood.

BRACHIALIS ANTICUS (L.). A muscle situated upon the front part of the arm, which assists the biceps flexor in bending the elbow-joint.

BRAIN. The mass of nervous substance contained in the cavity of the cranium.

BRONCHI. The two passages into which the trachea divides at the top of the chest, and which supply the lungs on each side with air.

BRONCHIAL TUBES. The small tubes into which the bronchi divide as they enter the substance of the lungs.

BUTYRINE. An oleaginous substance which gives the peculiar flavor to the butter of cow's milk.

CALCANEUM (L. *calco*, to kick or trample). The heel-bone.

CANINE Teeth (L. *canis*, a dog). The pointed teeth situated just outside the incisors, one on each side in each jaw; so called because they are very prominent in the dog, as well as in other carnivorous animals.

CAPILLARY Blood-vessels (L. *capillus*, hair). The smallest blood-vessels, intervening between the arteries and the veins; so called from their minute or hair-like dimensions.

CARBONIC ACID (L. *carbo*, a coal). A gas formed in respiration and exhaled with the breath; so called because it is also produced from burning coals.

CARDIA (Gr. καρδια, *kardia*, the heart). The upper orifice of the stomach, through which the food enters from the œsophagus; so called because it is situated near the heart.

CARNIVOROUS Animals (L. *caro*, *carnis*, flesh; and *voro*, to devour). Animals that feed upon flesh.

CARIES (L. *caries*, rottenness). The partial decay of a bone or tooth.

CAROTID Arteries. The two main arteries which run upward, on each side of the neck, to supply the head and brain.

CARTILAGE. A firm elastic substance, like India-rubber, attached to the bones in various parts of the body.

CASEINE (L. *caseus*, cheese). The albuminous ingredient of milk; so called because, when coagulated, it forms the substance of cheese.

CATALYSIS (Gr. καταλυω, *kataluo*, to dissolve or demolish). A peculiar chemical change, in which the ingredients of a substance are altered or decomposed by the mere contact of another substance.

CELL. A minute form, occurring in animal and vegetable tissues, sometimes hollow and sometimes solid, and varying in shape, being globular, flattened, cylindrical, or irregular.

CELLULAR TISSUE. A tissue consisting of loosely interwoven fibrous bundles, which is placed between the muscles and other contiguous parts.

CEREBELLUM (literally, the "Little brain"). A convoluted ganglion, smaller than the cerebrum, and situated at the back and lower part of the brain.

CEREBRUM. The largest portion of the brain, filling all the front and upper parts of the cranium.

CEREBRO-SPINAL Nervous System. That portion of the nervous system consisting of the brain, the spinal cord, and the nerves belonging to them, through which the body is brought into nervous communication with the external world.

CHEST. The upper part of the trunk of the body, inclosed by the spinal column behind, the ribs on the sides, and the breast-bone in front.

CHONDRINE (Gr. χόνδρος, *chondros*, cartilage). The albuminous ingredient of the cartilages.

CHOROID COAT (Gr. χωριον, *chorion*, the vascular part of the skin, and εἶδος, *eidos*, form). A brownish-black membrane forming one of the envelopes of the eyeball; so called because it resembles the skin in vascularity.

CHYLE (Gr. χυλὸς, *chulos*, juice). The white, milky-looking fluid produced in the small intestine by the digestion of fatty substances.

CILIARY Nerves. A set of slender nerves, ten or fifteen in number, which are given off from the ophthalmic ganglion, and are finally distributed to the muscular fibres of the iris.

CINERITIOUS Nervous Matter (L. *cinis*, *cineris*, ashes). The gray or ash-colored substance of a nervous ganglion.

CIRCULATION. The movement of the blood in a continuous round

or circuit, from the arteries to the veins and from the veins back again to the arteries.

CLAVICLE (L. *clavis*, a key). A slender bone, shaped somewhat like a key, placed horizontally at the bottom of the neck, between the top of the breast-bone and the point of the shoulder. The collar-bone.

CLOT. The firm, red, opaque, jelly-like mass, formed by the coagulation of the blood, and consisting of the fibrine and blood globules mixed.

COAGULATION. A process of solidification peculiar to the albuminous substances.

COCHLEA (L. *cochlea*, a snail-shell). A portion of the labyrinth of the ear, consisting of a double tubular canal, winding spirally round a central axis, like a snail-shell, and containing the terminal ramifications of the auditory nerve.

COLLAR-BONE. See CLAVICLE.

COLON (Gr. κωλύω, *kōluo*, to restrain). The name given to the large intestine; because its contents move slowly.

CONCHA (L. *concha*, a shell). The cup-shaped depression in the middle of the external ear, leading to the mouth of the auditory meatus.

CONGESTION (L. *congero*, *congestum*, to heap up). An unusual filling of the vessels of a part with blood.

CONJUNCTIVA (L. *conjungo*, to join). The thin membrane which covers the front of the eyeball and lines the inner surface of the eyelids; so called because it joins the eyelids to the eyeball.

CONSTRICTORS OF THE PHARYNX (L. *constringo*, to tie up, as in a bundle). Three muscles which are wrapped round the pharynx so as to compress this canal and force the food through it from above downward.

CONTRACTION. The active shortening of a muscle or muscular fibre.

CONVULSION (L. *convello*, to tear). A violent and involuntary contraction of some or all of the muscles of the body and limbs.

CORNEA (L. *cornu*, a horn). A firm, transparent, and colorless layer, forming the front part of the eyeball, through which the light penetrates into the interior; so called from its resemblance to horn in texture and consistency.

CRANIAL Nerves. The nerves connected with the brain; so called because they emerge through openings in the cranium.

CRANIUM. The bony case containing the brain.

CREATINE and Creatinine (Gr. κρέας, *kreas*, flesh). Two substances produced in the process of excretion, formed in the tissue of the muscles and discharged from the body by the kidneys.

CRIBRIFORM (L. *cribrum*, a sieve). Perforated with many little holes, like a sieve.

CROWN of a tooth. That portion of the tooth which projects above the jaw.

CRYSTALLINE. The albuminous ingredient of the crystalline lens.

CRYSTALLINE LENS. A transparent circular body, rounded on its front and back surfaces, situated in the eyeball, just behind the pupil.

It serves to concentrate the light passing through it at the surface of the retina.

DECUSSATION (L. *decusso*, to cut crosswise). A reciprocal crossing from side to side.

DEGLUTITION. The act of swallowing.

DEVELOPMENT. The process by which the body passes through successive changes or stages of growth, from infancy to adult age.

DIAPHRAGM (Gr. διάφραγμα, *diaphragma*, a partition). The vaulted muscular sheet which separates the cavity of the chest from that of the abdomen.

DIGESTION. The liquefaction and preparation of the food in the alimentary canal.

DUCT. A narrow tube, usually destined to convey away a secretion from the gland in which it is produced.

EMULSION (L. *emulgeo*, to milk). A permanent mixture of oil, minutely divided, with a watery liquid; so called because it is white and milky in appearance.

ENAMEL. The dense calcareous covering of the crown of a tooth.

ENDOSMOSIS (Gr. ἔνδον, *endon*, within, and ὠθισμός, *ōthismos*, an impulsion). The force by which a fluid is made to penetrate an animal substance or tissue.

EPITHELIUM (Gr. ἐπὶ, *epi*, upon, and θηλή, *thēlē*, a nipple). A layer of soft cells, covering the surface of the lining membranes and certain parts of the skin.

EUSTACHIAN TUBE. A membranous canal, extending from the fore part of the tympanum of the ear to the side of the pharynx, and serving to establish a communication between the cavity of the tympanum and the external atmosphere; from Barthelemi Eustachi, an Italian anatomist of the sixteenth century.

EXCRETION (L. *excerno*, *excretum*, to purge out). The process by which the waste materials of the body are changed and eliminated. A substance or fluid so produced is also called AN EXCRETION.

EXPIRATION. The act by which air is carried out of the lungs in breathing.

EXTENSOR Muscle. A muscle which serves to straighten or extend a joint.

EXTERNAL EAR. The trumpet-shaped expansion on the side of the head which serves to conduct sounds toward the mouth of the auditory meatus. It is that part commonly called the "ear."

FACIAL Nerve. The seventh cranial nerve, distributed to the muscles of expression in the face.

FEMUR. The thigh-bone.

FENESTRA (L. *fenestra*, a window). The name sometimes given to a perforation in the walls of a cavity, as, for instance, the "oval fenestra" in the outer wall of the vestibule of the ear.

FERMENT. A substance which causes fermentation.

FERMENTATION (L. *fermentesco*, to rise, to puff up). A process of catalysis, by which bubbles of gas are formed in the fermenting substance.

FIBRINE. An animal matter found in the blood, which has the property of coagulating spontaneously; so called because, when coagulated, it has a fibrous texture.

FIELD OF VISION. The circular space in front of the eyes within which objects can be perceived.

FLEXOR Muscle (L. *flecto*, *flexum*, to bend). A muscle which serves to bend a limb or joint.

FOCUS (L. *focus*, a fireplace). The spot at which the rays passing through a lens are brought together.

FOLLICLE. A little bag or sac, formed of an animal membrane, and usually opening by a minute orifice at one extremity.

FOLLICLES OF LIEBERKÜHN. The simple tubular follicles of the lining membrane of the small intestine; so called from John Nathaniel Lieberkühn, a Prussian anatomist of the eighteenth century, by whom they were first described.

FONTANELLE (Italian *fontanella*, a little fountain). A name given to two spots in the cranium of infants, where the ossification of the skull is not yet complete, and where the pulsations of the brain can be felt through the soft parts, like the bubbling of water in a fountain.

FORAMEN (L. *foramen*, a hole). A perforation; usually in a bone.

FUNCTION (L. *fungor*, *functus*, to perform). The office performed by any organ of the body.

FUNGUS. A very simple kind of vegetable growth, formed entirely of cells.

GALL-BLADDER. A sac or reservoir, communicating with the main biliary duct, in which a portion of the bile is stored up during the intervals of digestion.

GANGLION (Gr. γαγγλίον, *ganglion*, a tumor). A collection of gray nervous matter containing nerve-cells, and acting as a nervous centre.

GANGLION OF MECKEL. A small ganglion belonging to the sympathetic nervous system, situated beneath the floor of the skull, and giving off nerves which are distributed to the inner part of the nasal passages and to the muscles of the hanging palate; from Meckel, a German anatomist of the eighteenth century.

GASSERIAN GANGLION. A considerable ganglion, situated upon the fifth or "trigeminal" nerve, within the cranium, at the level of its division into three main branches; so called from Achilles Pirminius Gasser, a German anatomist of the sixteenth century, by whom it is said to have been discovered.

GASTRIC TUBULES. The elongated tubular follicles of the lining membrane of the stomach, by which the gastric juice is secreted.

GASTROCNEMIUS Muscle (Gr.). A strong muscle situated upon the back part of the leg, which serves to draw the heel upward.

GELATINOUS (L. *gelatus*, congealed). Like jelly in consistency.

GENERAL CIRCULATION. The movement of the blood through the various tissues and organs, from the arteries to the veins, as distinguished from the circulation through the lungs or any other particular organ.

GENERAL SENSIBILITY. The sensibility residing in the skin and some of the lining membranes, by which we acquire the perception of

the simpler physical qualities of external objects; such as their consistency, texture, temperature, etc.

GERMINATION (L. *germino*, to bud). The first growth or sprouting of a seed.

GLAND. An organ composed of follicles, lobules, and ducts, with blood-vessels interwoven, which produces a secretion from the materials of the blood.

GLANDULE. A little gland.

GLOSSO-PHARYNGEAL Nerve (Gr. γλῶσσα, *glōssa*, the tongue, and φαρυγξ, *pharunx*, the throat). The ninth cranial nerve, which is distributed to the back part of the tongue and to the pharynx.

GLOTTIS. The narrow opening or crevice in the upper part of the larynx, by which it communicates with the throat.

GLUTEN. The albuminous matter of wheat flour; so called from its adhesive and glutinous consistency.

GRANULE. A little grain.

GUSTATORY Nerve (L. *gusto*, to taste). The special nerve of the sense of taste, being a branch of the third division of the fifth cranial nerve.

HANGING PALATE. A muscular curtain, hanging downward from the back part of the roof of the mouth, which partially separates the cavity of the mouth from that of the pharynx.

HELIX (Gr. ἕλιξ, *helix*, any thing twisted or convoluted). The outer border of the external ear, which is rolled or convoluted inward.

HEMIPLEGIA (Gr. ἥμισυς, *hēmisus*, half, and πλήσσω, *plēsso*, to strike). A paralysis of one lateral half of the body, and the limbs on the corresponding side.

HEPATIC Vein (Gr. ἧπαρ, *hēpar*, the liver). The vein which collects the blood from the liver and carries it onward to the heart.

HERBIVOROUS Animals (L. *herba*, grass, and *voro*, to devour). Animals that feed upon vegetable matters.

HYALOID Membrane (Gr. ὕαλος, *hualos*, glass, and εἶδος, *eidos*, form). A very thin, transparent, and colorless membrane, which lines the inner surface of the cavity of the eyeball.

HYDROPHOBIA (Gr. ὕδωρ, *hudōr*, water, and φόβος, *phobos*, fear). A disease induced by the bite of a mad dog, and characterized by extreme irritability of the spinal cord, so that the least external impression causes violent reflex convulsions, especially of the muscles of deglutition; so called because the animals and men affected by it were supposed to have an especial dread of water.

HYGIENE (Gr. ὑγίεια, *hugieia*, health). The study of the laws of health and the means of its preservation.

HYPOGLOSSAL Nerve (Gr. ὑπὸ, *hupo*, under, and γλῶσσα, *glōssa*, the tongue). The motor nerve distributed to the muscles of the tongue; so called because the trunk of the nerve runs for some distance beneath the bottom of the tongue.

INCISORS (L. *incido*, *incisum*, to cut). The four front teeth in each jaw; so called because they are provided with a sharp edge and are adapted for cutting.

INFANT (L. *infans*, not speaking). The child under two years of age; so called because he can not yet use articulate language.

INSENSIBLE TRANSPIRATION. The name given to the perspiration when produced in its usual moderate quantity, so that it instantly evaporates; consequently being imperceptible or "insensible."

INSPIRATION. The act by which air is drawn into the lungs in breathing.

INTERCOSTAL Muscles (L. *inter*, between, and *costa*, a rib). The muscles which are situated between the ribs, and which move the ribs in respiration.

INTERCOSTAL Nerves. The spinal nerves which supply the intercostal muscles.

INTERNAL EAR. That part of the auditory apparatus consisting of the labyrinth, its membranous bag and lymph-like fluid, with the ramifications of the auditory nerve; all contained within the substance of the petrous bone.

INTESTINAL JUICE. A viscid secretion produced by the lining membrane of the small intestine.

IRIS (L. *iris*, the rainbow). The perforated muscular curtain situated within the eye, in front of the crystalline lens; so called from its variegated color.

IRRITABILITY. The property by which the nerves or other organs are thrown into excitement by any stimulus applied to their substance.

IVORY. A very dense bony substance, forming the greater part of the teeth.

KERATINE (Gr. κέρας, *keras*, horn). The albuminous ingredient of the hair and nails; so called because the same substance is the ingredient of horn.

LABYRINTH. A cavity, of singular and complicated form, situated in the substance of the petrous bone, and containing the terminal ramifications of the auditory nerve.

LACHRYMAL CANALS (L. *lachryma*, a tear). Two narrow canals or ducts, an upper and a lower, leading from the inner corner of the eyelids toward the nose, and serving to convey away the tears from the surface of the eye.

LACHRYMAL GLAND. A lobulated gland, situated in the upper and outer part of the orbit of the eye, in which the tears are secreted.

LACTEALS (L. *lac*, milk). The lymphatic vessels of the small intestine, which become filled with white, milky-looking chyle during digestion.

LACTIC ACID. The acid produced by the souring of milk. It also exists in the gastric juice.

LARGE INTESTINE. The last five feet of the intestine; so called on account of its capacity, being considerably wider than the small intestine.

LARYNX (Gr. λάρυγξ, *larunx*). The cartilaginous box situated at the top of the windpipe, through which the air passes from the throat into the trachea.

LIGAMENT (L. *ligo*, *ligare*, to bind). A fibrous band or cord, serving to attach two bones to each other.

LINE OF DISTINCT VISION. The straight line extending in front of each eye, within which alone the eye can perceive objects distinctly.

LOBULE. A collection of little follicles or vesicles, or any division of a glandular organ communicating with a single duct.

LYMPH. A transparent colorless fluid, absorbed by the lymphatic vessels from various tissues of the body.

LYMPHATIC Vessels. A set of very thin, delicate vessels, which absorb the lymph from the tissues of the body and convey it inward toward the centre of the venous system.

MALLET. The outermost of the three small bones in the tympanum of the ear, having the form of a mallet, and attached to the membrane of the tympanum.

MARGARINE (Gr. *μάργαρον*, *margaron*, a pearl). A fatty or oleaginous substance, which is intermediate in consistency between stearine and oleine.

MARROW. A soft vascular substance contained in the cavities of the bones.

MASSETER Muscle (Gr. *μασσάομαι*, *massaomai*, to chew). A strong muscle situated upon the side of the face, which moves the lower jaw from below upward in mastication.

MASTICATION. The grinding up or comminution of the food by the action of the teeth.

MASTICATOR Nerve. The motor branch of the third division of the fifth cranial nerve, distributed to the muscles of mastication.

MEATUS (L.). A passage or canal.

MEDULLA OBLONGATA. A nervous mass of an oblong shape, situated at the lower part of the brain, and giving off many of the cranial nerves. It contains the ganglion of respiration.

MEIBOMEAN Glands. The glands situated on the inner surface of the cartilages of the eyelids, by which the oleaginous secretion of the lids is produced; from Henry Meibom, a German anatomist of the seventeenth century, who described the structure of the eyelids.

MEMBRANE. A thin and flexible expansion of tissue.

MEMBRANE OF THE TYMPANUM. A fibrous membrane stretched across the bottom of the external auditory meatus, and forming the outer wall of the tympanum.

MESENTERY (Gr. *μέσος*, *mesos*, in the midst, and *ἔντερα*, *entera*, the entrails). A broad membrane by which the intestines are attached to the spinal column.

MILK Teeth. The first set of teeth, twenty in number, which make their appearance during infancy; so called because the food at that time consists principally of milk.

MOLAR Teeth (L. *mola*, a mill). The side and back teeth, which are adapted for grinding the food, like mill-stones.

MOTOR Nervous Fibres. Those nervous fibres which convey the stimulus to motion from the nervous centres outward to the muscles.

MUCUS. A ropy lubricating secretion, produced by the follicles and glandules in various parts of the body.

Musculine. The peculiar albuminous ingredient of the muscular fibres.

Nasal Duct. A duct which receives the tears brought from the eye by the lachrymal canals, and discharges them into the cavity of the nose about its middle portion.

Nerve. A white cord composed of nervous fibres or filaments.

Nerve-cells. Rounded cells, often with slender prolongations running out from them, found in the gray substance of the nervous ganglia.

Nervous Centre. A collection of gray nervous matter, which receives impressions and originates the nervous impulses.

Nervous Fibre or Filament. A white thread of minute size, forming the substance of the nerves, and having the power of conducting the nervous stimulus.

Nervous System. The entire collection of all the organs composed of nervous tissue, namely, the ganglia and the nerves, with all their connections, throughout the body.

Neuralgia (Gr. *νεύρον*, *neuron*, a nerve, and *ἄλγος*, *algos*, pain). A painful affection produced by irritation of the sensitive nerves, without manifest disease of the other tissues.

Neurilemma. The fibrous sheath by which the filaments of a nerve are enveloped, and which protects them from injury.

Nitrogen. A gas having but little chemical activity, which forms about four fifths of the bulk of the atmosphere.

Nucleus (L. *nucleus*, a kernel). A round or oval spot, which is found upon certain cells, as, for instance, epithelium-cells and nerve-cells.

Nutrition. The internal process of nourishment of the body or any of its parts.

Œsophagus (Gr. *οἴω*, *οἴσω*, *oio*, *oiso*, to carry, and *φάγω*, *phago*, to eat). The muscular tube which conveys the food from the mouth to the stomach. The gullet.

Oleine (Gr. *ἔλαιον*, *elaion*, oil). An oleaginous substance which is fluid at ordinary temperatures.

Olfactory Nerves (L. *olfacio*, to smell). The special nerves of the sense of smell.

Ophthalmic Ganglion (Gr. *οφθαλμὸς*, *ophthalmos*, the eye). A small ganglion belonging to the sympathetic nervous system, and situated in the back part of the orbit of the eye, from which the ciliary nerves are given off to the iris.

Optic Nerves (Gr. *ὄπτομαι*, *optomai*, to see). The special nerves of the sense of sight, distributed to the interior of the eyeball.

Optic Thalami. Two nervous ganglia, situated beneath the cerebrum and behind the striated bodies; so called because they were formerly supposed to be the origins of the optic nerves.

Optic Tubercles. A pair of small rounded ganglia, situated near the middle part of the brain, from which the optic nerves take their origin.

Orbicularis Muscle of the Eye. The muscle surrounding the

opening of the eyelids, by which the eye is suddenly and forcibly closed, as in the act of winking.

ORBIT. The bony cavity beneath the forehead in which the eyeball is situated.

ORGAN (Gr. ὄργανον, *organon*, an instrument). Any part of the body which is adapted to perform a particular service, such as the heart, the stomach, the brain.

OSSIFICATION (L. *os*, *ossis*, a bone, and *facio*, to make). The conversion of cartilage or other soft tissue into bone.

OSTEINE (Gr. ὀστέον, *osteon*, a bone). The albuminous ingredient of the bones.

OXYGEN. A gas forming one fifth part, by bulk, of the atmosphere, which is essential to respiration.

PANCREAS. A gland situated in the upper part of the abdomen, near the lower border of the stomach.

PANCREATIC JUICE. The secretion produced by the pancreas.

PANCREATINE. The albuminous ingredient of the pancreatic juice.

PAPILLA (L. *papilla*, a nipple). A minute conical prominence or elevation upon the surface of an animal membrane; thus the "papillæ" of the tongue.

PARALYSIS (Gr. παραλύω, *paraluo*, to loosen). A suspension or abolition of the power of sensation or motion; more frequently of both.

PARAPLEGIA (Gr. παραπλήσσω, *paraplēsso*, to strike with derangement). A paralysis of the lower limbs and lower half of the body.

PAROTID Gland (Gr. παρὰ, *para*, near, and οὖς, ὠτὸς, *ous*, *ōtos*, the ear). The salivary gland situated just in front of the ear.

PAR VAGUM (L.). Literally, the "wandering pair." A name given to the pneumogastric nerves, on account of their long course and varied distribution.

PEDUNCLES of the Brain. Two rounded bundles of nervous fibres running upward and forward from the base of the brain, and terminating, on each side, in the substance of the cerebrum; so called from the botanical term "peduncle," which signifies the stalk of a flower.

PELVIS (L. *pelvis*, a basin). The hip-bone; so called because it is like a basin in shape.

PEPSINE (Gr. πέπτω, *pepto*, to cook, to disintegrate by cooking). The most important ingredient of the gastric juice, which acts as a ferment in the digestion of the food.

PERISTALTIC Action (Gr. περιστέλλω, *peristello*, to wrap round). The peculiar movement produced by the successive contraction of circular muscular fibres wrapped round a cylindrical tube, as in the œsophagus or the intestine.

PERSPIRATION (L. *per*, through, and *spiro*, to breathe or exhale). The watery secretion exuded upon the surface of the skin.

PERSPIRATORY Glands. Small glandular bodies, in the form of a coiled tube, situated immediately beneath the skin, by which the perspiration is secreted.

PETROUS Bone (Gr. πέτρα, *petra*, a rock). One of the bones forming the base of the skull, and containing the internal ear and the tympanum; so called from its stony hardness.

PHARYNX (Gr. φαρυγξ, *pharunx*, the throat). The muscular passage leading from the back part of the mouth to the œsophagus.

PHRENIC Nerve. The nerve of the diaphragm.

PHYSIOLOGY (Gr. Φύσις, *Phusis*, Nature; and λόγος, *logos*, a discourse). The study of the natural actions of the living body.

PLEXUS (Gr. πλέκω, πλέξω, *pleko*, *plexo*, to weave or plait together). A network of any thing interwoven, as of blood-vessels or nerves.

PNEUMOGASTRIC Nerve (Gr. πνεύμων, *pneumōn*, the lungs, and γαστὴρ, *gasteer*, the stomach). The tenth cranial nerve, distributed principally to the lungs and the stomach.

PONS VAROLII (L.). Literally, the "bridge of Varolius." A transverse band of nervous fibres passing in a curved form from one side of the cerebellum to the other, and spanning the longitudinal fibres of the medulla oblongata, like an arched bridge spanning a stream; so called from Varolius, an Italian anatomist of the sixteenth century, who first described it.

PORTAL Vein (L. *porta*, a gateway). The venous trunk formed by the union of all the veins coming from the intestine, and which conveys the blood to the liver.

PTERYGOID Muscles (Gr. πτέρυξ, πτέρυγος, *pterux*, *pterugos*, a wing). Two muscles situated between the "pterygoid" or wing-like projections of the base of the skull and the lower jaw. They give to the jaw a lateral or grinding movement in mastication.

PTYALINE (Gr. πτύελον, *ptuelon*, saliva). The albuminous matter of the saliva.

PULMONARY (L. *pulmo*, the lungs). Relating or belonging to the lungs.

PULMONARY Artery. The great artery which receives the blood from the right ventricle of the heart and carries it toward the lungs.

PULMONARY CIRCULATION. The movement of the blood through the lungs, from the pulmonary artery to the pulmonary veins.

PULMONARY Veins. The veins which bring the blood from the lungs to the left auricle of the heart.

PULP of a Tooth. The soft vascular papilla or prominence around which the harder portions of the tooth are deposited.

PULSATION of the Heart. The entire act, or movement, of the successive contraction and relaxation of the auricles and ventricles.

PULSE (L. *pulso*, to beat). The rhythmical distension of an artery by the impulse of the blood from the heart.

PUPIL. The circular perforation in the centre of the iris, through which the light reaches the deeper parts of the eye.

PYLORUS (Gr. πυλωρὸς, *pulōros*, a gate-keeper). The lower orifice of the stomach, through which the food passes into the intestine; so called on account of a circular band of muscular fibres by which the passage is guarded.

RADIAL Artery. An artery which passes along the front of the wrist, at its outer part, to supply the palm of the hand.

RECEPTACULUM CHYLI. Literally, the receptacle of the chyle. A small sac or dilatation situated at the commencement of the thoracic duct.

Rectum (L. *rectus*, straight). The last portion of the large intestine; so called because it is nearly straight, in comparison with the remainder of the intestine.

Recurrent Nerve (L. *recurro*, to run back). The inferior laryngeal branch of the pneumogastric nerve; so called because it is given off from the main trunk of the pneumogastric at or near the top of the chest, and then returns in a direction from below upward, to reach the larynx in the upper part of the neck.

Reflex Action of the Nervous System. An action by which the impression received by a nervous centre through the sensitive nerves is again reflected outward through the motor nerves, under the form of a stimulus to movement.

Regimen. The systematic regulation of the food and drink.

Relaxation. The inactive condition of a muscle or a muscular fibre.

Rennet. The prepared tissues and fluids of the calf's stomach, used for coagulating milk in the manufacture of cheese.

Respiration (L. *re*, denoting repetition, and *spiro*, to breathe). The process by which the atmospheric air is introduced into the lungs for the renovation or arterialization of the blood.

Retina (L. *retis*, a net). The membranous expansion of the optic nerve in the interior of the eyeball.

Root of a Tooth. The elongated portion of the tooth which is imbedded in the jaw.

Saccharine. Containing or consisting of sugar.

Saliva. The fluid secretion produced by various glands and poured into the cavity of the mouth.

Salivary Gland. A gland which produces saliva.

Sclerotic Coat (Gr. σκληρὸς, *sklēros*, hard). A firm and resisting fibrous envelope, forming the outer coat of the eyeball.

Sebaceous Matter (L. *sebum*, tallow). A substance of oleaginous composition, but nearly solid in consistency, like tallow.

Secretion (L. *secerno*, *secretum*, to separate). The separation or production from the blood of a fluid destined for a special purpose. The fluid so produced is also called a secretion.

Semicircular Canals. Three narrow curved passages, excavated in the substance of the petrous bone, and communicating with the cavity of the vestibule. They contain a clear colorless lymph, and a membranous sac corresponding to them in form, upon which a portion of the filaments of the auditory nerve are distributed.

Semilunar Ganglion (L. *semi*, half, and *luna*, the moon). An important ganglion of the sympathetic nervous system of a semilunar or half-moon shape, situated behind the stomach.

Semilunar Valves. The three festooned or bag-like valves, of a half-moon shape, situated on each side of the heart, at the entrance of the great arteries.

Sensation. The conscious perception of an impression made upon the nervous system.

Sensitive Nervous Fibres. Those nervous fibres which convey impressions from without inward to the nervous centres.

SERUM (L. *serum*, whey, buttermilk). The clear, watery, amber-colored fluid which separates from the clot after the coagulation of the blood. It contains, beside water, albumen and mineral substances.

SMALL INTESTINE. The first twenty-five feet of the intestine immediately following the stomach; so called on account of its small calibre, being only an inch and a half in width.

SOLAR PLEXUS (L. *sol*, the sun). A radiating plexus or network of sympathetic nerves, spreading from the neighborhood of the semilunar ganglion outward, like the rays of the sun, to be distributed to the various organs in the abdomen.

SOLEUS Muscle (L.). A muscle situated on the back part of the leg, which assists the gastrocnemius in drawing the heel upward.

SPECIAL SENSE. A sense by which we receive particular sensations, differing from those of general sensibility; such as those of sight, hearing, taste, and smell.

SPINAL CANAL. A long cavity containing the spinal cord, inclosed in the bones of the spinal column.

SPINAL COLUMN. The back-bone.

SPINAL CORD. A cylindrical mass of nervous matter situated in the cavity of the spinal canal, connected with the brain above, and giving off the spinal nerves from its two opposite sides.

SPINAL Nerves. The nerves connected with the spinal cord.

SPINE. A projecting point or ridge of bone.

SPLEEN. A very vascular organ situated within the abdomen, near the left extremity of the stomach.

STEARINE (Gr. στέαρ, *stear*, suet, fat). A fatty or oleaginous substance, which when pure is solid at ordinary temperatures.

STEREOSCOPE (Gr. στερεὸς, *stereos*, solid, and σκοπέω, *skopeo*, to examine). A box containing two different pictures of the same object, so arranged that, seen together, they produce a deceptive appearance of solidity.

STIRRUP. The innermost of the three small bones in the tympanum of the ear, having the form of a stirrup, and attached to the membrane of the oval fenestra.

STRIATED BODIES. Two oval ganglia situated, one on each side, at the under part of the cerebrum; so called because when cut open they present a striated appearance, owing to the white nervous fibres passing through the gray substance of the ganglion.

SUBCLAVIAN Vein (L. *sub*, under, and *clavis*, a key). The great vein bringing back the blood from the arm and side of the head; so called because it is situated underneath the *clavicle* or collar-bone.

SUBLINGUAL Gland (L. *sub*, under, and *lingua*, the tongue). A salivary gland situated beneath the tongue.

SUBMAXILLARY Gland (L. *sub*, under, and *maxilla*, the jaw). A salivary gland, situated beneath the angle of the jaw.

SYMPATHETIC NERVOUS SYSTEM. That portion of the nervous system consisting of a double chain of small ganglia, situated in front of the spinal column, and the nerves belonging thereto, by which a nervous communication is established between the internal organs of nutrition.

TEMPORAL Artery. A small artery which passes upward just beneath the skin in front of the ear, on each side, to supply the temples.

TEMPORAL Muscle. A fan-shaped muscle, situated upon the side of the head (on the temples), and attached to the lower jaw, which it moves from below upward.

TENDON. A fibrous cord by which a muscle is attached to its bone.

TETANUS (Gr. τέτανος, *tetanos*, a stretching or extension). A disease characterized by severe convulsions of the voluntary muscles, in which the body and limbs are forcibly extended or straightened.

THAUMATROPE (Gr. θαῦμα, *thauma*, a wonder, and τροπὴ, *tropee*, a turning). A toy consisting of a revolving card with a number of pictures of the same object in different positions, the effect of which is to make it appear as if the object were in rapid motion.

THORACIC Duct (Gr. θώραξ, *thōrax*, the chest). A narrow tube running from below upward within the back part of the chest, which is the main trunk of the lymphatic vessels.

TIBIA. The principal bone of the leg, below the knee.

TIC DOULOUREUX (French). Literally, the "painful spasm." Neuralgia of the fifth cranial nerve or of some of its branches.

TISSUE. Any substance or texture in the body formed of various elements, such as cells, fibres, blood-vessels, etc., interwoven with each other.

TRACHEA (Gr. τραχεῖα, *tracheia*). The cartilaginous and membranous tube leading downward from the larynx to the top of the chest. The windpipe.

TRAGUS. A short ridge-like elevation in the front border of the external ear.

TRANSFUSION of the Blood (L. *trans*, over, across, and *fundo*, to pour). The operation of introducing fresh blood from the vessels of one living animal or man into those of another.

TRIGEMINAL Nerve (L. *tres*, three, and *geminus*, alike). The fifth cranial nerve; the great sensitive nerve of the face; called "trigeminal" because it divides, just before leaving the cavity of the cranium, into three nearly equal branches.

TROCHLEARIS Muscle (Gr. τροχιλέα, *trochilea*, a pulley). The upper oblique muscle of the eyeball; so called because its tendon passes through a pulley-like ring.

TUBER ANNULARE (L.). Literally, the "annular" or "ring-like swelling." A rounded protuberance of nervous matter, situated at the base of the brain, just in front of the medulla oblongata.

TUBULE. A little tube.

TURBINATED Bones (L. *turbo*, a whirling or convolution). Three rolled or convoluted plates of bone attached to the outer wall of each nostril.

TYMPANUM of the Ear (L. *tympanum*, a drum). The cavity of the ear situated between the labyrinth and the bottom of the external auditory meatus, closed internally by the membrane of the oval fenestra and externally by the membrane of the tympanum.

URATE OF SODA. A substance formed of the combination of an

animal acid with soda, produced, like urea, in the process of excretion, and discharged from the body by the kidneys.

UREA. A substance produced in the process of excretion, and discharged from the body by the kidneys.

UVULA (L. *uva*, a grape). Literally, a "little grape." A conical fleshy appendage attached to the lower border of the hanging palate.

VALVULÆ CONNIVENTES. The valve-like folds or projections of the lining membrane of the small intestine.

VASCULAR. Containing or belonging to blood-vessels.

VEIN. A vessel serving to convey the blood from the various organs inward to the heart.

VENOUS Blood. The dark-colored blood contained in the right side of the heart and the veins of the general circulation.

VENTILATION. The method by which the air is renewed in apartments and dwellings.

VENTRICLE (L. *ventriculus*, a little stomach). The larger and thicker chamber of the heart, on each side, which receives the blood from the corresponding auricle and discharges it into the artery.

VENTRICULAR Valves. The valves situated in the heart at the entrance from the auricles to the ventricles.

VERMICULAR Action (L. *vermis*, a worm). The muscular contraction of certain parts of the alimentary canal; so called because it resembles a crawling or worm-like motion.

VESICLE (L. *vesicula*, a little bladder). A small rounded sac or bag composed of a thin animal membrane.

VESTIBULE. A rounded chamber in the petrous bone, forming a portion of the labyrinth.

VILLI (L. *villus*, hair, or the nap of shaggy cloth). The minute filamentous projections from the inner surface of the lining membrane of the small intestine.

VITREOUS Body (L. *vitrum*, glass). A colorless glassy-looking substance, of gelatinous consistency, which fills the cavity of the eyeball behind the crystalline lens.

VOCAL CHORDS (L. *vox*, *vocis*, the voice). Two elastic bands of fibrous tissue, forming the lateral edges of the glottis. Their vibrations, communicated to the air, produce the sound of the voice.

VOLITION (L. *volo*, to will). The nervous act by which we intentionally excite the muscular contractions.

WISDOM TEETH. The four posterior molar teeth; so called because they do not make their appearance until the age of from seventeen to twenty years.

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Park was thinking

of Adam I guess

when God took

of his ribs and

made Eve.